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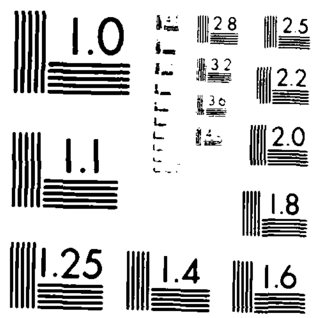

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The Impact of Petroleum, Synthetic and Cryogenic Fuels on Civil Aviation

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June 1982

Final Report

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

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16. Abstract Energy demands arise largely from demand for liquid fuels, rather than energy in other forms. Future demand for liquids is seen to increase in the world, rather than to decline. Similarly, major concerns are with the price of fuel and assurance of its availability, rather than with resource depletion. The cost of producing most petroleum is far below the market price, but world demand can be met only with marginal costs near the world price. Production marginally above or below demand therefore can affect prices strongly.

Because international affairs and economics affect fuel prices and availability more than technology and resources, and because aviation is a minor element in international and national energy, aviation fuel must be viewed in a broad perspective. This report seeks to provide such a perspective.

Fuel costs are now the dominant item in airline operations, profit and loss, and survival. While aviation fuel consumption is inconsequential in national and international energy, it is vital to aircraft operators. Fractional percentage improvements can be cost effective. Significant fuel economy potential still remains in the air traffic control system; much larger gains can be had with new aircraft. But competition for capital funds and financing new equipment will be increasingly difficult.

Through treaty agreements, the U.S. will remain vulnerable to crude oil delivery disruptions for many decades. At least one major disruption should be expected in any five-year period.

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Table of Contents

Dedication

This report is dedicated to R.C. (Sparky) Sebold, who was corporate Vice President-Engineering of Convair during the remarkable period when it produced a stable of revolutionary products ranging from Atlas, the first ICBM, to Redeye, the first shoulder-fired anti-aircraft missile.* The criterion throughout this report is to provide the information as it is thought he would want it. Although he may not take it to the board room, it is hoped he will find it interesting.

* This product array also included the B-36 Peacemaker, first intercontinental bomber, the B-58 Hustler, first supersonic bomber; the F-102, begun as a rocket-powered fighter, becoming the Delta Dagger, first U.S. delta-wing combat aircraft, the F-106 Delta Dart, which recaptured the world speed record from the USSR, the XFY-1 Pogo, first VTOL fighter, the XF2Y Sea Dart, only supersonic seaplane, the Terrier, first operational fleet air defense missile, and the Convair 240/340/440 and 880/880M/990 series transports. *The Convair 990, built when Jet A was ten cents or less a gallon, is still the fastest cruising subsonic airliner.*

During development of the Atlas, his advisory committee was chaired by Theodore von Karman; it included Charles Critchfield, George Gamow, I.I. Rabi, Edward Teller and Fred Whipple.

A

PREFACE

This report is addressed to aviation executives and managers concerned with the influence of aviation fuels on their plans and decisions. It seeks to assist those in aircraft and engine manufacturing, in airlines, airport operation, aviation fuel supply, general aviation, trade associations, government offices, study teams, finance, publications, academia and elsewhere, who are concerned with these matters.

Prepared essentially for the Federal Aviation Administration (FAA), it is intended as a staff report. Aviation organizations seeking orientation on fuel matters, which cannot assign their own staffs to scrutinize aviation fuel matters in depth, are expected to find this material useful. It has been prepared and printed at the Mellon Institute's Energy Productivity Center to avoid distraction by FAA activity, as well as by FAA, Department of Transportation and government policies. Hopefully, it may develop value to the Government through observations which otherwise might not have surfaced.

The report is presented in two volumes. Volume 1 reports findings from the study. An earnest effort is made to distinguish between fact and opinion although, admittedly, the margin is sometimes thin and may not have been apparent to the author.

Even Chapter 1, EXECUTIVE SUMMARY, may include a bewildering coverage of subjects and information. Although undesirable in a staff report, this diversity is unavoidable in an arena affected by so many factors. A user should be exposed to the full breadth of fuel and energy at least once, to acquire perspective and a feel for what may be and what may not be reasonable.

As will be seen, aviation fuel is a small factor in a field of large and powerful forces. Its future is at the mercy of various developments: political, sociological, economic and technical. An aviation executive should be aware of these forces and their influences, even when he is unable to influence them directly.

This report was intended to be largely technical. Other factors are brought in as necessary, which is often, since they usually predominate. The report aims to provide perspective, rather than laborious detail, although detail is used for illustration and to show the depth of some subjects.

Volume 2 largely includes further discussion, analysis, justification and background for the Volume 1 material. It is offered for those who may not accept parts of Volume 1 at face value, or who wish more detail. Since all matters related to energy are in rapid transition, Volume 2 provides a background for updating as new information becomes available.

On October 20, 1981, The Georgetown Center for Strategic and International Studies (CSIS), in connection with its Energy and National Security Project, held a one-day forum on aviation fuels at which the outline of this report was briefed and discussed Approximately forty representatives participated from the groups to whom this report is directed. As a part of the program, ten experts were invited to present their views on the most critical and controversial issues. Because of its direct, intense and authoritative attention to the material of this report, the CSIS forum and its participants are referenced often. A synopsis of that meeting and its tape record are included as Appendix C.

With scant exposure to the subjects of fuel and energy prior to this project, a great deal of guidance in its preparation was essential. The list of contributors is so extensive that ACKNOWLEDGEMENTS are given in Appendix B.

How to Use This Report

Because factors affecting aviation fuel have such wide scope and extensive interactions, this material is offered at several depths of coverage. Users are invited to succeeding depths of detail according to their purposes at any given time:

Lightest Coverage

1. Conclusions — The broad outlook on aviation fuels.
2. Recommendations — Actions suggested by the study.
3. Volume 1
   a. Chapter 1, EXECUTIVE SUMMARY's Board Room Briefing.
   b. Body of Chapter 1, EXECUTIVE SUMMARY.
   c. Board Room Briefings for succeeding chapters. (Select chapters of interest by titles).
   d. Body of succeeding chapters.
4. Volume 2.
5. References of Volumes 1 and 2.

Heaviest Detail

Notice:

It has been concluded more productive to implement and promote conclusions and recommendations from Volume 1, than to complete formal preparation of Volume 2. Consequently, Volume 2 will not be printed as a document.

Drafts of Chapter 1, "Forecasting and Modeling" and Chapter 2, "Oil Prices, Politics and OPEC," of Volume 2 are available on request. Contents of the author's files and notes for the remainder of Volume 2 are available for discussion or reference. Inquiries may be addressed to:

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or telephone (202) 426-8722. Interest in the conclusions and recommendations of Volume 1 will be especially appreciated.

Conclusions

1. Petroleum fuel should be available for aviation at competitive prices for at least 20-30 years, probably for 30-50 years.

2. ***Under stable world economic and political conditions***, near-term energy and real fuel prices should rise less than 2% per year above general inflation. The probability for 0% rise is greater than for 2% rise.

3. Forecasters of international affairs unanimously predict that world politics and economics will not remain stable. One severe fuel disruption is virtually certain within five years and three such disruptions are expected in any ten-year period.

4. Forecasters disagree on the effects of these disruptions. About half believe they will be moderate because of increased world conservation and oil production. The other half believe that disruptions will be drastic and that crude-oil prices will double.

5. There is pressure to accept jet fuel with broader specifications, particularly during crude supply disruptions. Lighter fuel fractions cause no operating penalty, but their safety impacts will require careful consideration. Heavier fuel fractions would degrade aircraft operations and compete with the larger diesel and heating markets.

6. Modern and future refineries can deliver desired products (including specification jet fuel) from any natural crude or synthetic crudes. Refining costs will be higher with lower-quality crudes, although these extra processing costs should decrease over five to ten years. Aviation fuel users should consider how much fuel degradation they may accept for higher operating and maintenance costs.

7. OPEC crude-oil production costs are about a dollar a barrel and the world average is around two dollars. Marginal production costs in non-OPEC countries and the U.S. are generally much higher. Capital costs for oil exploration and drilling will continue to rise. Capital costs for synthetics are typically about 75% of product costs. Success of alternative fuels depends on specific situations. Taxes, regulations and politics transcend natural or technical factors in fuel costs.

8. While renewable energy is "free," capital costs for its concentration, conversion, transmission and use are high. Renewables may contribute in favorable local or regional situations, but are unlikely to affect national or international energy before the next century.

9. There is no shortage of fuel resources, particularly in the U.S. The problem is liquid fuels, largely because transportation requires liquids. Emerging countries will increase demands for liquids since they cannot afford electrical or other distribution systems.

10. Capital costs for fuels will increase, regardless of world economics and politics, and become a larger segment of world financing. One countervailing factor may be world natural gas production. The U.S. might revolutionize its entire fuel/ energy/ capital situation by removing regulatory, tax and other institutional barriers against natural gas.

11. In the ten-year period 1972-82, aviation fuel prices rose more than 1000% and fuel consumption became a dominant factor in airline economics. Conservation measures are cost-effective. Airlines will have difficulty in financing the fuel-efficient aircraft they need for survival.

12. Competition will increase for capital to finance energy exploration and development, synthetic fuels, industrial plants, and emerging nations. Aircraft provide less security on the investment than previously.

13.Liquid hydrogen is more attractive to foreign nations than the U.S. High-priced in the U.S. economy, foreign economies may produce it by subsidized nuclear or other power. The U.S. should follow hydrogen's technical, and especially its economic potential. Liquid methane could become economically attractive both in the U.S. and the world.

14. Methanol may emerge as an attractive fuel (not in aviation), and particularly as a universal chemical feedstock. Advances in catalytic processing should eventually permit production of almost any fuel from methanol feedstocks at competitive prices.

Recommendations

1. The U.S. should unshackle domestic energy production, particularly natural gas. Natural gas can displace petroleum as fuel and feedstock, reducing U.S. oil imports. Since natural gas production capacity exceeds demand, the first step should be removing restrictions against its use. A parallel effort should encourage U.S. Enhanced Oil Recovery (EOR).

2. U.S. aviation should protect against oil supply disruptions. Airlines should explore fixed-floor purchase agreements with producers for a reliable supply of shale oil, which produces excellent Jet A fuel. They should cooperate with the DoD in this effort.

3. Jet fuel users should resist heavier fuel specs, or consider them only with reduced pricing pressures. Tests for effects of heavier fuels on ***current*** engines should be emphasized rather than ***changes*** needed for long-term use of heavier fuels. *Long-term use of heavier fuels* is undesirable and should be unnecessary.

4. U.S. aircraft industry will not compete with foreign consortia such as Airbus Industrie unless NASA aeronautical support is regenerated. The U.S. should consider how the "short-range transport" can be built *in the* U.S., rather than abroad.

5. Aviation gasoline will become *more scarce and expensive*. General Aviation should investigate liquid methane as a cheaper fuel.

6. The FAA and the National Weather Service should develop a national, 4-dimensional, real-time, aviation weather and forecast network. With nominal off-the-shelf equipment and minimal operating costs, at least $2-3 hundred million can be saved in direct annual airline fuel costs alone.

7. U.S. aviation should investigate if Jet A delivered at closer to the 100°F flash point would improve its price or availability and whether greater benefits could be achieved below 100°F.

8. The U.S. and individual states should consider whether it makes sense to encourage energy sources which can make only high-priced or limited contributions to the market. In contrast, domestic resources (natural gas and EOR) which could improve the U.S. economy and reduce oil imports, remain heavily burdened with obstacles. If unburdened at various jurisdictional levels, the U.S. and Free-World situations could be significantly improved.

Introduction

"In 1846, the United States was illuminated by whale oil, town gas, and candles. Seven hundred thirty-six ships were at sea collecting whale oil as the liquid fuel of the day. By 1855, the gradual extermination of the sperm whale led to an astronomical price of $60 a barrel for whale oil.* Meanwhile, in France in 1838 and later in Scotland shale oil was being produced. European immigrants based on this experience started small shale oil operations in the Ohio Valley and by 1859, fifty-five such plants operating over 100 retorts were in business. In 1859," — the first oil well was completed in Pennsylvania. "By the following year oil dropped to 10 cents a barrel and the oil shale plants were out of business."[1-1]

From 1860 until 1973, the price of crude oil remained around or below $2 a barrel. For more than five generations, the world became accustomed to low, stable energy prices; many assumed that was the way the world was created.

In early 1982 the marginal price of crude oil on the world market is above $30 per barrel. The cost of producing Saudi oil is still probably about twenty-five cents per barrel and the OPEC average cost is less than a dollar. The world average production cost is about $2 per barrel.[1-2] By contrast, it now costs about $5-10 a barrel to produce oil from the North Sea and $15 to land it ashore, $25 for Alaskan oil delivered in the U.S., $20 from the U.S. continental shelf, and an average of about $25 per barrel for enhanced oil recovery from old fields in the U.S. Experts agree[1-3] that the capital investment for producing synthetic fuels in the U.S. now runs up to $100,000 and more for each barrel per day capacity. That equates to $27.50 per barrel of capital costs alone if the investment is recovered in a ten-year period. It does not include interest costs on the investment.

With this kind of disparity between production costs, as well as between production costs and world prices, there must remain a strong potential for further crude oil price instability. During the ten-year period 1972-82 alone, the price of jet fuel rose by more than a factor of ten. Future fuel prices are likely to be determined more by international economics, politics and even military affairs, than by geology, engineering or production capacity.

What is the probability of another technical revolution, such as low-cost oil production by Col. E.L. Drake in 1859? As will be seen, there is considerable probability that more oil and other resources will be produced, but at costs approximating marginal oil prices.

Edward Teller[1-4] has commented, "Our knowledge of the processes by which energy sources are formed is incomplete, but our list of energy sources may be complete. We have looked far back into the history of the universe. And we probably know enough about fuels to say that no more completely novel sources of energy will become available in practice. . . . A hundred years ago, nuclear energy was not even a dream. At that time the claim that we know all fuels would have been wrong. But at that time a good scientist would not have made such a claim. He would have realized that he did not understand the energy source of the sun. . . . The universe is big, and usable energy sources are enormous. Man and his needs are tiny. There is enough energy even on this small planet where most of us seem to be confined for the foreseeable future, a most uncertain time span."

From a purely technical standpoint, solar energy, nuclear fission and fusion, and probably methane hydrates are essentially unlimited on this globe, as far as man's needs are concerned. The problem is in the cost of producing and converting energy sources. When capital costs approximate 75% of the total costs for producing a fuel, and when these capital costs approach or exceed $100,000 per barrel per day capacity, no new source is likely to be offered on the market at lower than the prevailing price level. New sources should be produced only when they can be profitable at that level.

On the other hand, world demand has now stabilized to high prices so that any appreciable increase in world oil production during the next few years would bring about a short-term decrease in prices. In the much longer term, fuel prices should rise slightly faster than inflation because of increasing resource value as well as production costs. Technological developments could offset these increases, as could natural gas and EOR production in the U.S.

Having commented about future resources and prices, a few words should be offered about forecasting in general. Forecasts are based either on mathematical extrapolations of past experience, or by proposing a concept for some future time and then analyzing interrelationships within that scenario. Neither approach is apt to give us a good reading on the future of fuels. The recent past has been so turbulent that no mathematical projection can be reliable. Anyone who accepts a scenario for some time in the future, inherently has doubtful need for pragmatic analyses. About the best we can do is to hypothesize alternatives, assuming that there is no major disruption in the interim. Or, select major disruptions and try to analyze their implications. In any case, we must keep foremost in mind that these analyses cannot predict the future of fuel and certainly not influence it.

* In 1855 dollars' The Library of Congress advises that this $60 in 1855 equates to $615 in November 1981

Of all the bodies that have analyzed energy or fuel, perhaps the most prestigious is the World Energy Conference, about which more will be said later. It is noteworthy that the *Foreword* of their latest report[1-5] begins, "During the last few years a great number of studies dealing with the global resource situation of energy raw materials have been compiled. These studies have demonstrated very clearly that a comprehensive and universally acceptable inventory and analysis is not as yet possible. The reasons for this situation are geological. To this day, the geological knowledge of our planet is not as yet comprehensive enough to enable the geological analyst to accurately and completely quantify the resources of conventional raw materials. This applies even more so to renewable energy resources, the technology of which is largely still in the development stage."

This study addresses two main concerns with aviation fuels: first, fuel price, the effects of supply and demand, the various sources and forms of supply, alternatives, and the conservation measures which reduce demand. Second, the likelihood, the nature, and the effects of disruption in foreign crude oil deliveries to the United States.

Chapter 1

Executive Summary

Board-Room Briefing — The BRB is designed for an executive just alerted to report to the board room, where the effect of fuel in his program is already being discussed. He has no time to take stock, ask questions, or receive explanations. He needs the bottom line now and, at his peril, hopes he can extemporize the details. He uses a BRB only if he has implicit faith in his staff, but then without qualification; his staff can expect reassignment if they lead him astray. With that understanding, a BRB begins each chapter of this report.

BRB — No.1 — Aviation Overall

1. Civil aviation fuel represents about 6% of the petroleum consumed in the U.S. Aviation gasoline is only about 5% of aviation fuel.

2. Aviation has little effect on the petroleum market and is a minor component of most U.S. refinery operations. Aviation fuel is produced by less than 20% of U.S. refineries, generally the larger ones, which represent about 45% of U.S. refinery capacity. It is not the major component of their output but, since it carries a premium price, it is significant to their production slates.

3. Mid-East and OPEC crude oil, as well as from Mexico, Canada, and old U.S. wells, is generally produced at costs far below world price. In Saudi Arabia, production costs are probably still below 25 cents per barrel. New Free-World crude outside OPEC is produced at costs reasonably close to the market and new finds may be expected to be at comparable costs. Although many new finds may surface within the next ten or more years, they will offer little relief in price unless they are fairly big and relatively easy to produce.

4. World demand for petroleum has declined and stabilized to reflect current high prices. World production capacity currently exceeds consumption; over-production would reduce the price of oil in the short term. So the price of crude can go either way: up if there is moderate reduction in production; flat if supply conditions remain stable; down if production is increased.

5. Fuel conservation has been gratifyingly effective in the past few years; it has been especially effective in aviation. Other factors remaining equal, the 1980 reported airline financial loss would have been twenty times greater without conservation achieved since 1973. Fuel costs have risen from about 25% of airline Direct Operating Costs (DOC) to over 50%. Fractional percentage savings in fuel consumption are critical to airline profitability.

6. Airline fuel consumption should decline through 1983. Forecasts from 1983-2000 vary from about 5% average annual increase, to flat, to some possibility of decrease. The ***percentage*** of U.S. petroleum used by aviation is almost certain to rise. But this effect is due far more to the decrease in net petroleum used by the U.S., rather than from the expected increase in jet fuel consumption.

7. Refineries must operate at a profit; products sold at a loss must be supported by other products sold at higher prices. In general, aviation fuels can command higher prices, offsetting lower profits or losses in products such as residual oil. Jet fuel has been relatively easy to make and distribute. Aviation fuels will continue to be produced as long as the market and prices are compatible. But the aviation gasoline market may become so thin in twenty or so years that it will assume the role (and price) of a specialty product. In terms of distribution, it is already a specialty product.

8. Disruption of U.S. foreign crude supply is not only likely, it is probable. Foreign analysts agree a serious disruption should be expected within five years. Three serious disruptions are expected in any ten-year period, until the U.S. develops strong enough domestic supply sources to be independent of foreign disruptions. This "independence" probably cannot be developed by any means until after 2000, while our trading partners and allies will still remain vulnerable for an indefinite period. In effect, the U.S. can reduce its vulnerability but does not appear able to eliminate it.

9. Although the Free World will remain vulnerable to severe crude oil disruptions for some years, future disruptions may not be as traumatic or raise the price of fuel as much as in the past. Some analysts disagree, expecting the next disruption could bring a complete cessation of Mideast shipments. To them, a doubling of price in a severe disruption would not be surprising.

10. Assuming international stability, aviation fuel prices should remain nearly the same as today, or increase at one or two percent in real dollars, for as long as twenty, thirty, even fifty years. But smoke from the 1979-80 price rise hasn't completely cleared and the market may not have stabilized. Realistically, it may never stabilize. Prices will rise steadily further if capital, production and processing costs continue upward, relative to the rest of the economy. Taxes and regulatory policies, even sociological affairs, may affect mid-term prices as much as the supply/demand balance.

11. Although U.S. oil inventories have been higher in the past few years, the U.S. petroleum processing and supply system runs on minimum reserves; some flexibility is required for flow contingencies. In case of disruption in foreign supplies, only the Strategic Petroleum Reserve (SPR) and private supplies can cushion the effect significantly. The SPR is being filled now near

maximum rate, but cannot offer potential protection until the end of 1982. It will be little more than a token until about 1986-88.

12. The National Petroleum Council (NPC) reports that U.S. refineries are capable of producing the desired product mix in all assumed crude disruption scenarios. A relaxation in jet fuel specification flash point would have no adverse effect on aircraft performance, but would decrease some safety aspects by an undetermined amount. Expected further significant decline in auto fuel demand will make these lighter fractions increasingly available to the market, including aviation. Lighter fractions yield lower percentages of jet fuel and attempts to restore yield by adding heavier fractions will push freeze points upward. A small increase in freeze point — 5°C — may cause little effective penalty.

13. Future crude oils are expected to be increasingly heavy. Any significant relaxation in jet fuel spec freeze point would tend to decrease aircraft performance, increase engine fuel consumption, increase exhaust smoke, and increase maintenance and replacement costs. It would move aviation fuel closer to the diesel market, which is expected to increase significantly in demand. Due to other marketing influences, it is doubtful that such a spec relaxation would decrease jet fuel prices, but it might improve availability.

14. Directly or indirectly, U.S. government regulatory and tax policies, and public attitudes toward energy programs, are likely to affect the course of aviation fuel prices and supply far more than any direct activity in aviation. Nevertheless, aviation must pursue fuel conservation, as well as means to stabilize fuel prices and assure a reliable supply. (Individual airlines and others should consider establishing domestic sources such as shale oil to minimize the impact of future crude-oil disruptions).

15. Through their effects on the petroleum market, motor transport and even stationary power trends will influence aviation fuel prices more than will aviation activities. Developments such as low-cost methanol or increased use of natural gas, could affect aviation by backing petroleum out of the stationary or ground-vehicle liquid-fuel market, releasing petroleum further for aviation.

16. As petroleum prices rise, U.S. shale oil appears to be the next least costly fuel source, although capital investments will be vast. Shale oil refines to excellent jet fuel. Coal synthetic liquids appear secondary to shale oil in costs and availability. Coal liquids are suitable for high-octane gasoline, but not so readily for jet fuel. But coal can be gasified and catalytically converted to any fuel. Today the process is expensive, but this is a fertile field for future fuel technology. Catalytic conversion of natural gas may also develop as a major liquid fuel source.

17. The U.S. holds a tremendous source of oil shale, capable of producing more liquid fuel than the entire Mid-East oil source. Few other developed nations possess a comparable source for hydrocarbon fuels. The U.S. also has immense sources of coal, peat, and probably of natural gas. It still has respectable petroleum reserves. Most of the Free World and particularly Europe and Japan, will regard alternatives to petroleum in an entirely different light than will the U.S.

18. Carbon dioxide in the world's atmosphere is expected to double within fifty years. No one knows if it will accentuate the earth's "greenhouse" heating effect seriously or, if it does, whether the net effect will be favorable or unfavorable, or to whom. Both the U.S. and Britain are analyzing those questions vigorously and definitive answers should emerge in less than two years. But it may take more than twenty years of observation to verify the forecasts. By that time, action would be largely academic; the process is generally expected to be irreversible.

Because they lack hydrocarbon fuels or feedstocks, and with popular interest in the greenhouse effect, some foreign nations may develop a strong interest in hydrogen fuel that may puzzle many in the U.S. (As discussed later, hydrogen production from hydrocarbon stocks releases much carbon dioxide. But hydrogen produced from water-splitting releases no CO_2, while the only products from hydrogen combustion are clean water vapor and some NO_x).

19. As petroleum prices rise, hydrogen may be proposed as a universal fuel, particularly for world uniformity and availability in aviation. Hydrogen can be produced from water using any energy that is locally available. Existing aircraft could be modified, at considerable cost, to operate on liquid hydrogen. New aircraft, originally designed for hydrogen, can expect advantages in performance, reliability and engine life. Safety should be comparable to avjet aircraft. Aircraft DOCs with hydrogen fuel may be comparable to those with avjet. These DOCs include airport costs for liquefaction and handling fuel, which are considerable and are the primary obstacle to hydrogen implementation. These DOC projections are also 20-30 years in the future and may shift relative to avjet-fueled aircraft before the time arrives.

Hydrogen costs are relatively high and unlikely to be reduced drastically by technical improvement. But industrial development, use of byproducts, and energy accounting methods (including taxes) could conceivably adjust the price of hydrogen to be directly competitive with petroleum fuels. Other nations may use different accounting for costs of hydrogen.

20. The world's present energy posture is largely a problem of liquid fuels and their prices. Looking indefinitely into the future, it appears the world will at least retain, or probably *increase* its dependence on liquid fuels. Various energy forms and conversion methods, including electricity produced from renewable sources, are likely to develop locally, where they are economically competitive. But they are not likely to reduce the need for liquid fuels, particularly in Less Developed Countries.

This is sufficient exposure for the introductory Board Room Briefing. The remainder of this EXECUTIVE SUMMARY adds to the foregoing BRB notes. Its content deals with two concerns: first, fuel prices based on supply and demand, second, the prospects for and consequences of disruptions in foreign crude deliveries. In turn, supply and demand considers fuel alternatives, then conservation measures which can affect demand.

Aviation Fuel Outlook

Aviation passenger traffic is expected to grow at an average rate of about 5% per year into and through the 1990s. World air traffic will grow somewhat faster. But the U.S. air traffic controllers' strike and economic recession will doubtless reduce U.S. traffic during 1982 and most of 1983.

Aviation fuel demand will grow more slowly than air traffic; it could even hold fairly steady or decrease, even with increasing traffic. The present consensus is for a slow net increase in aviation fuel demand, perhaps one to two percent average annually to 2000. However, the near term is definitely retarded by the strike's effect on Air Traffic Control (ATC) capacity. Economic sluggishness and continued vigor in aviation fuel economy may further reduce aviation fuel demand so that the prospect, at least through 1983, should be a net decrease.

Whether aviation fuel demand increases or decreases in the long run, it will increase in percent of U.S. petroleum consumption because of the continued expected fall-off in demand for automotive fuel. But the total effect of aviation fuel on the national picture is small, except at those refineries which produce jet fuel, and because of its potentially increasing competition with diesel and other large middle-distillate customers.

As has now been clearly proved, world prices of crude oil and fuels are subject to market supply/demand balance. That balance has been adverse to buyers in the past few years such that any decrease in production could trigger inordinate short-term increases in price. World demand has now stabilized at a lower level with higher prices and, apparently for the next year or so, excess production capacity will have to be managed to prevent a fall in market prices. As more petroleum comes on line from Mexico, Africa and possibly the Far East, OPEC and specifically Saudi Arabia should find it increasingly difficult to maintain prices.

Fuel costs today are ranging up to 60% of airline direct operating costs (DOCs) and fuel prices are unlikely to fall enough under any assumptions to relieve this sensitivity. Airlines will continue to pursue small fuel economies and more attention will be directed toward saving fuel in the air traffic control (ATC) system.

The capability for saving some $300 million per year in aviation fuel by essentially an off-the-shelf improvement in the air weather information system should receive active attention and support. One of the problems is that this situation is a direct responsibility of neither the FAA nor of the National Weather Service. Each organization is already over-committed for its funds available.

World Energy Outlook

The International Institute of Applied Systems Analysis (IIASA) at Laxenburg, Austria recently completed a long-range assessment[1-6] of the world energy situation which is probably as comprehensive and as authoritative as any made. It was actively supported by twenty countries, including OPEC and Third World countries, but primarily by the national academies of the U.S. and the USSR. One of its conclusions was that any forecast involving human activity which projects beyond fifteen years, will probably encounter some completely unpredictable events which affect the outcome of the forecast more than any factor considered. Further, petroleum authorities advise that no prediction concerning oil or fuel should be taken seriously beyond five years. The IIASA report was released in early 1981; it therefore could not fully appreciate world fuel conservation which had already been achieved and which is likely to develop much further.

With those qualifications in mind, ***IIASA's conclusions*** are paraphrased:

1 The world's present "energy transition" will not be concluded in fifty years; it will take at least seventy. Capital investment needs cannot be met and the sociological problems cannot be overcome in fifty years.

2. There will be no single replacement for petroleum. A wide variety of practical energy types will emerge and all must be exploited to meet world energy demands.

3. For more than a hundred years, the world will still be heavily dependent on hydrocarbon fuels such as coal although, after about seventy years of capital investment, nuclear and solar power could provide a stable base.

4. The Less Developed Countries (LDCs) will need much more energy per unit GNP than industrial countries because of their lower efficiency in use and transportation.

5. The cost of electrical transmission and storage will seriously limit LDC use of electricity, whether produced by nuclear, solar, or hydroelectric power. LDCs will be vitally dependent on liquid fuels, as will transportation around the world. World dependence on liquid fuels will not decrease; it will remain or probably become more critical.

6. The world petroleum distribution system will be increasingly filled with methanol as feedstock and fuel and, eventually, by hydrogen. Hydrogen should become the dominant liquid fuel by 2100, perhaps sooner.

7. Because of need for liquid fuels, in the long run coal and nuclear power should be used more to produce liquid fuels than for heat and electricity.

8. Worldwide capital investments for energy production will be major. By 2000, about 100% more in direct, real funds will be required per unit of energy, while indirect costs will rise by 250%. The cost of energy in LDC budgets will rise four times as fast as in budgets of industrialized nations.

9. The world energy future causes serious concern, particularly for LDCs. But its technology and economics should be feasible. IIASA did not resolve the sociological or political problems, which they believe are formidable. They expect these problems may not be solved and that much hardship and many casualties may result.

10. Carbon dioxide will double in the atmosphere by 2030. By the time it is known whether the effect is serious, it may be essentially irreversible.

Petroleum Resources

New Finds — Available U.S. petroleum discovery and production data cover over a hundred years. Any statistical analysis of these data indicates that U.S. petroleum production peaked in 1970 and that world production will peak in the 1990s. Many forecasters, largely those with mathematical or geological backgrounds, believe the data are valid, symmetrical and that the ensuing exhaustion of petroleum is inevitable and imminent. Others, largely with economic backgrounds, believe as fervently that past history cannot project future events. More specifically, they point out that a new era has emerged since the low, stable prices over most of the past hundred-year period, as seen in Fig. 1-1. Higher prices are certain to produce oil that was uneconomical or marginal in earlier markets, as well as to stimulate development in new areas.

Also significant, and with agreement by geologists, optimistic forecasters point out that much of the world is yet unexplored for petroleum; much oil is being found at depths lower than indicated by conventional geology; new techniques now permit making these finds. In the U.S. and elsewhere, particularly offshore, many promising areas have been closed to exploration, let alone to production. This report sides with the optimists and believes that oil company 1981 annual reports bear out this view but, if not conclusively enough, almost surely in the reports for 1982.

On one hand, the quantity of new oil found may only cushion disruptions. If produced at costs near the world's marginal price, it will not lower prices. Higher new production costs could even stimulate higher prices. But if produced below the marginal price or if enough is produced to challenge OPEC control, fuel prices could be brought lower. Since markets are influenced by

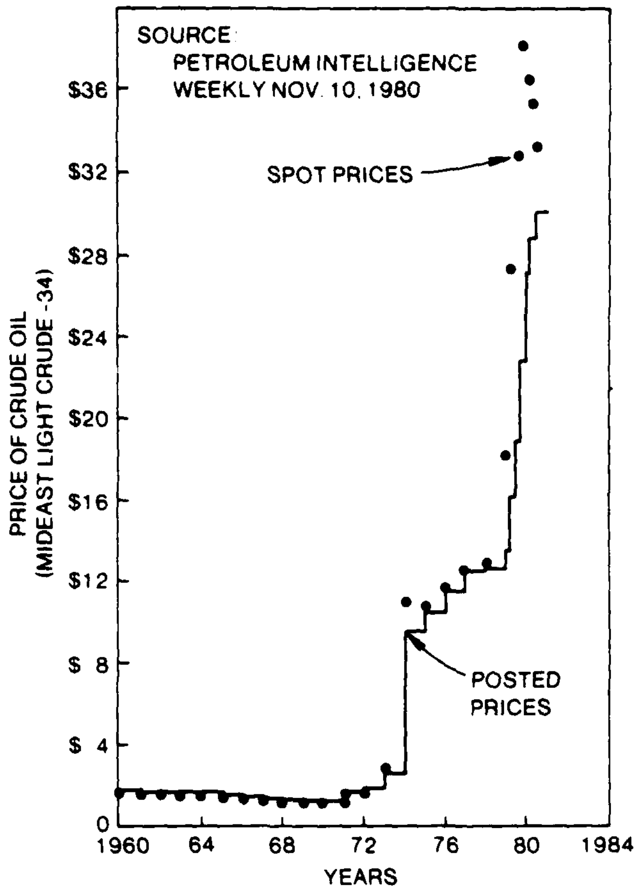

Figure 1-1

psychology, while excess production is already being restrained, significant oil finds or increase in production potential could depress market prices.

Enhanced Oil Recovery — In the U.S. and the world, on the average only about 30% of the oil in existing fields is produced before yield rates become uneconomical and production is stopped. EOR is risky and expensive, but today it can typically produce another 10% to 20% from existing fields. Particularly with present tax provisions, EOR is generally regarded less attractive to developers than wildcat drilling. Advanced technology, particularly CO_2 injection, may increase the prospects for EOR, but it is still expensive, risky and inhibited by regulations and taxes.

The significant thing about EOR is that it is here and now, identified rather than speculative. In the U.S., it offers some potential relief from world oil pricing and import disruptions. This is more a political issue than a technical or economic matter. If the U.S. decides to exploit its existing resources by encouraging EOR, the greatest benefit would be realized during this decade.

Jet A Specifications — Some see the world trend toward heavier crudes and the U.S. trend toward increased percentage of Jet A (kerosene) consumption as a need to produce more jet fuel from a barrel of oil. In some scenarios, more jet fuel per barrel would be expected to reduce pressures on jet fuel prices and to increase its availability, particularly in times of foreign delivery disruptions. Less stringent processing per barrel is expected to make more product available and deliveries easier.

If Jet A specifications are relaxed on the light end, lowering the flash point below 100°F, engine performance is not sacrificed and may be improved to a slight degree. The only significant question is decreased safety: in handling, crash-fire survival and lightning-strike vulnerability, which have not been adequately quantified. (It should be noted that many other nations operate with Jet B, which has no specified flash point and is usually near 0°F. But they do so at an acknowledged risk). The FAA has contracted for a test laboratory to establish the characteristics of fuels with lower flash points, but the tests are currently deferred. Because further expected decrease in automotive fuel demand should release more light components to the fuel market, aviation fuel might benefit by adopting flexibility in this direction. The major issue would probably be in resolving the safety question with appropriate authorities and with underwriters.

Relaxation of jet fuel specs on the heavy end introduces entirely different considerations. It does not affect fuel handling safety; however,by increasing freeze point, it will present the aircraft operator with a need to plan and monitor his (altitude) operations more closely to avoid fuel freezing. Heavier fuels produce dirtier combustion and exhaust products, more internal radiant heat and engine thermal problems. When infrequently flown at lower altitudes to avoid low temperature soak, the aircraft cruise performance penalty can be significant. Depending on particulars of the the spec change, newly designed engine parts and aircraft fuel systems could be required.

The conclusion of this report is that a trend toward heavier jet fuel could cancel some of the progress in fuel conservation and performance achieved with new aircraft and engines now on order. This issue is now being debated, handicapped by a lack of tentative data on fuel price effects. Even the effects on fuel availability are subjective and speculative. But the entire subject of heavier jet fuel may be a moot issue for three reasons.

First, engine and aircraft manufacturers point out that their existing products and those under development will be in service for many years to come and, without costly modification, they probably cannot accept heavier fuel for continuous operation. Second, fuel producers cannot assure that a relaxed spec could produce a lower-priced fuel. They offer no opinion on whether any price reduction, if achieved, would offset aircraft operating losses or whether a price reduction could be sustained over the depreciation life of new equipment. Third, due to the expected decrease in demand for gasoline, as compared to increases for diesel fuel and other middle distillates, prices may rise in the middle-distillate range while they drop for the lighter products. A spec for heavier jet fuel might drift it into closer competition with formidable markets.

Lastly, new refineries are being built and old refineries are being modified to process heavy petroleum fractions into light products. Some observe that these processes are more expensive, which they are in the short run. But, particularly with the bright outlook for developments in catalysts, process costs should drop in five to ten years and, in the long run, may be accomplished at little increase or in lower net costs. While one may not want to bet heavily in favor of technological progress, it is probably a worse choice to bet against it, particularly when closely linked to economic progress.

The pressure for heavier jet fuel remains unconvincing. But in an arena as volatile and unpredictable as fuels, this question

may recur often as new conditions unfold. It is desirable for the aviation industry to consider a coordinated position on this point, at least to clear up the expectations of refiners. In the short term, say less than five years, it may be desirable to relax specs in favor of fuel availability. But refiners should get down to specifics. The Coordinating Research Council (CRC) is pursuing tests to determine the effects of heavier fuels on existing engines; results of these tests should be important in any price/cost/availability analyses.

At the same time, pending outcome of the deferred FAA-sponsored safety tests, airlines could ponder their use of a relaxed flash point for Jet A, or in emergency, use of Jet B (which is used in military aviation, by some foreign airlines, and has no flash point limit). Existing U.S. commercial engines and aircraft are certificated to operate on both Jet A and Jet B.

Aviation Gasoline

As has been mentioned, only 5% of aviation fuel used in the U.S. is gasoline, 95% being jet fuel. Gasoline is more important to the U.S. economy at present than its sparse use would indicate. No U.S. trunks use gasoline, but many smaller communities are dependent on commuter airlines for connection to the national network. About 50% of commuter traffic is gasoline-powered. About 85% of commuter airline passengers make connections with national carriers; that is, more than ten million passengers per year. So five million airline customers per year, or 3.5% of total U.S. passengers depend on aviation gasoline at some point in their travel.

In business aviation, a smaller percentage of traffic depends on gasoline. While about 23 million business passenger-miles are carried by corporate turbojets and turboprops at the longer ranges, about 8.8 million of the 44 million U.S. business-operated aircraft passengers per year depend on gasoline as their fuel. Adding the commuter and business gasoline passengers gives 14 million, or 4.5% of the U.S. total aviation traffic dependent on gasoline. And, of the total estimated business travelers in the U.S., 6% of them are dependent on gasoline.

Even though U.S. recreational and miscellaneous flying uses slightly more gasoline than that used in business flying, gasoline does not compete significantly with the jet market and it is small in comparison with gasoline used for other recreational activities, such as recreational vehicles or boating. For every gallon of gasoline used in the U.S., about two tablespoons are used in aviation.[1-7] The National Petroleum Council[1-8] recommends no regulation for general aviation gasoline during any of the emergency crude oil import disruption scenarios they have considered. If gasoline becomes scarce for commuter airlines or business aviation during an emergency, then it will probably be the responsibility of the aviation community to allocate gasoline within its ranks.

Aviation gasoline is produced in three grades and by only six U.S. refiners. World wide, the situation is even tighter. The Iranian refinery at Abadan, which was shut down by the Iran-Iraq war, supplied all the aviation gasoline for the Middle East, much of Africa, and large areas of India and Southeast Asia. Its closure has affected aircraft operations in Australia and New Zealand. But the problems of aviation gasoline availability and price are not due to refining capacity — there is excess — they are largely from its distribution to hundreds of small U.S. airports that dispense avgas.

Due to the wide variety of automotive fuels existing in the U.S., it is not practical to use conventional motor gasoline as a general substitute for aviation gasoline. However, it may be possible to produce motor gasoline to a controlled formula which, if distributed through the aviation gasoline network, would be suitable for the lowest grade of avgas, 80-octane. 80-octane serves only about 40% of the General Aviation fleet, the smaller aircraft. The larger aircraft in commuter airlines and business fleets typically require 100-octane, of which there are two grades, normal and low-lead. No auto gasoline could be suitable for these aircraft.

Demand for aviation gasoline will decline as more new aircraft use turbine engines and as new reciprocating or other small engines are developed to operate on jet fuel. As 100-octane availability becomes difficult and prices rise, aircraft operators may consider the alternative of liquid methane. Although an LCH_4 fuel system weighs no more than a gasoline system, the tanks require more space for its lower density and cryogenic insulation.

Therefore, depending on space available, conversion to LCH_4 may reduce the range of an aircraft. However, its fuel consumption rate should be decreased due to greater energy per pound, while maintenance is greatly improved because of its extremely clean combustion. Its performance number is equivalent to 120 octane and, on today's market, it sells for less than half the price of aviation gasoline, generally closer to a third the price. LCH_4 should be attractive now for short-range operators, such as for training, and for hub-and-spoke traffic systems. It can be used equally well in 80-octane and in 100-octane engines.

Natural Gas

Natural gas (methane) has little immediate potential in airline aircraft, although helicopters or a hub-and-spoke freight operation like Federal Express might find it profitable. Liquid methane is presently being tested in general aviation.

It is a cryogenic fuel; that is, it cannot remain liquid at room temperatures, even under high pressures. At atmospheric pressure, it liquefies at -259°F. In small quantities such as in 20-gallon automobile tanks, LCH_4 begins to boil off about ten days after filling and then at the rate of about a cubic foot of gas an hour. Since it carries a lower price per Btu, it may be economically attractive in aircraft at shorter ranges or in special applications. If found to be tremendously available and considerably cheaper than jet fuel in the future, it could conceivably be attractive for new commercial transports.

As with liquid hydrogen, existing transport aircraft could be modified to use liquid methane, LCH_4, but the modification would be expensive. Cryogenic insulation is impractical in wing-tank geometry and, since the fuel would have to be carried in large cylindrical fuselage tanks, the conversion is neither convenient nor cheap. In short-range, smaller aircraft, tanks presumably could be installed in the fuselage with less difficulty.

Methane is a more attractive fuel in ground transportation and U.S. use should increase on a selective basis. Compressed methane, as well as liquid methane and other liquefied gases are used much more extensively abroad in both industrial and automotive applications. Methane is a superior feedstock for conversion to methanol (methyl alcohol), generally cheaper than coal. Methanol may back significant amounts of petroleum out of both the ground transportation and the stationary fuel markets. Methanol's energy content per pound is about half that of kerosene, gasoline or liquid methane, so it is not attractive as an aviation fuel.

Particularly as catalysts are developed further, methanol offers a transportable feedstock which will be convertible to any desired liquid fuel. Methanol production is likely to flourish in many sectors of the world such as Alaska (now that the gas pipeline is deferred), North Africa, and the Middle East as a means for economical transport of excess natural gas. Small methanol plants can be used to salvage natural gas at remote oil- and gas-producing sites. (Under favorable conditions, small methane liquefaction plants could be used for the same

purpose).

Natural gas resource forecasts are more debatable than petroleum, although both optimists and pessimists agree that gas quantities are probably vast and considerably greater than petroleum. As wells are drilled deeper, more gas is found than oil. Far more energy is flared as waste natural gas in the Middle East today than is being produced as oil in Alaska.

Gas can be transported readily by pipeline, but is costly to liquefy because of the low temperature required. Methanol offers a transportation alternative, but the present industrial demand for methanol is small; petroleum is still the conventional chemical feedstock. It may be expected that world methanol production will rise rapidly to conserve wasted or otherwise unmarketable gas, paced by capital costs and the construction of methanol plants. Barge-mounted methanol plants may become common around the world. If its price drops, methanol demand should expand as both a chemical feedstock and as a fuel.

In the U.S., natural gas use is curtailed by a variety of regulations, taxes and institutional restrictions, much like enhanced oil recovery (EOR). Natural gas is obtainable from a number of sources. There is first conventional, associated gas, available because it is dissolved in most of the oil produced. There is also non-associated gas, produced from nominally oil or gas fields which have not or no longer produce oil.

Then there is gas available from six "unconventional" gas resources (UGR), which are not included in conventional oil-bearing geology. These UGR sources include coal seams, tight sands, deep basins, Devonian shale, geopressured brines, and methane hydrates. There is also another exciting new hypothesis of deep-earth gas, which is discussed with these others in Chapter 7. This diversity probably contributes to the divided political constituency for natural gas.

Much UGR will be expensive or impractical to produce, but there is a strong likelihood that the discovery and production of natural gas will greatly outstrip oil in the future. Relaxation or removal of institutional and tax constraints could improve the U.S. gas picture dramatically. A belief that U.S. domestic gas production could increase 50% by 2000 is gaining authoritative support. Speculation on world gas developments receives little attention because of the far greater interest in oil and the high cost of shipping gas overseas. Emergence of methanol can accelerate that interest.

Aviation Fuels from Alternative Sources

As has been seen, the problem with petroleum is not that its resource is limited (which it is), but that the world's presently largest and cheapest producers of crude oil are not its largest users. The demand from economies which use more oil than they produce has totalled near the world production capacity, although that situation has recently eased. But the result is that the world price of oil is far above production costs for much of the oil on the market. The subject of U.S. vulnerability is separate and is discussed later. In the present world market and far into the future, alternative fuels and energy sources will be practical only where they can compete in price with petroleum, considering all the capital and recurring costs of extraction, conversion, shipping, storing, handling, using, waste disposal, regulation and so on.

Therefore, alternative fuels which are competitive in some markets might be wholly impractical in others. Different nations may be drawn toward different solutions because of these circumstances. Aside from OPEC and countries like Mexico, Canada and the USSR, which are richly endowed with petroleum, the U.S. uniquely possesses a vast reserve of potential fuels and a variety of options for bringing them on the market in different forms.

The lowest-cost U.S. option, one with reserve resources sufficient for a hundred or so years and, fortunately for aviation, the one which can be most conveniently converted into synthetic jet fuel, is shale oil. As has been mentioned, the U.S. has more potential oil in shale than does the entire Middle East in its known and probable petroleum. Many thousands of gallons of shale oil have been produced in the U.S. in recent years, but not yet in commercial quantities and rates. The problems are formidable, particularly in capital investments, protection of the environment, and in development of supporting infrastructure.

Nevertheless, several billion dollars are currently being invested by organizations including the largest oil companies, and rapid progress is being made. The exit of Exxon and cessation of the Colony Project are serious blows to the industry but, in terms of the future, development of a viable shale-oil industry in the U.S. is still probable.

Cost projections are very elusive until the processes are proven (as Exxon attests), including all the steps to bring the product to market. There is understandably much trepidation because of the unproven extraction and production costs, the possible environmental and sociological costs, as well as the prospects for world oil prices. Since capital costs range up to 75% of the cost of fuel produced, interest rates and taxes cause much more concern than possible OPEC reaction. Its financial interests will strongly deter OPEC members from significant crude-oil price reductions.

After taxes, environmental effects, infrastructure and local controls, perhaps the greatest risk to synfuel development is cost control.

In 1978 the Department of Defense made a considered and conclusive selection of shale oil as its alternative to petroleum.[1-9] The DoD will not finance production in any way but, depending on production supported by the Department of Energy and private industry, has been testing the refining and use of shale oil as a substitute for standard jet fuel. The results have been resoundingly favorable.

So questions about shale largely address its mining, extraction costs and other pre-refining processes which contribute to its economic outcome. Shale oil, incidentally, promises to be cheaper than average oil produced by potential enhanced oil recovery (EOR), at least under the tax and regulatory structure which govern EOR today. Today the only EOR being produced is that which is relatively cheap, which accounts for its small quantity.

While gas can be synthesized from coal at prices some have believed competitive, liquid fuel from coal requires additional processing, more capital investment and more expenditure of energy. Certainly today, liquid fuels from coal are expensive. Consequently, shale oil is developing more rapidly than coal liquids. Where direct coal liquids are high in aromatics and process into high-octane gasoline, these same qualities make direct coal liquids less desirable as jet fuel feedstock. In contrast, shale oil is basically paraffinic, very low in aromatics, refines readily into high-quality jet fuel, and produces a high yield of middle distillates per barrel.

Production of high-grade jet fuel from coal today requires either of two expensive two-step processes. In one, the hydrocarbons can be extracted by a solvent, yielding a highly-aromatic liquid which must be expensively processed to the jet

fuel. An alternative is to extract gas from the coal by a conventional process and then pay the price to synthesize liquid fuel from the gas. But, with further development of catalysts in the future, it is possible that either of these processes might produce jet fuel at more competitive costs.

As solid kerogen is converted to shale oil by retorting from rock, it is of different composition than petroleum, is high in arsenic, iron and other metals, and in nitrogen, oxygen and other impurities. It is so viscous that it cannot be pipelined without further treatment. For this reason, most producers will catalytically treat their shale oil production with hydrogen at the site of the retort. If not treated for shipment, the impurities in raw shale oil must be reduced by coking or hydrogenation before it can be introduced into any conventional refinery. Otherwise it quickly poisons the refinery's expensive catalysts. After such pre-treatment, shale oil is comparable to high-grade crude and is very low in impurities. DoD special, pilot-sized refining tests in 1000-gallon lots have shown that yields of very high-grade jet fuel typically run from 40% to 75% of the barrel at competitive costs. For about 10% cost per barrel more, the shale oil can be refined to literally 100% or slightly more volume of jet fuel (Jet A + JP-4), due to further introduction of hydrogen into the process.

Start-up costs for a shale operation are staggering. The largest proposed project in progress is Chevron's, at a planned capacity of 100,000 barrels per day (BPD). This is about 10% of the U.S. daily jet fuel used and consequently about 0.5% of U.S. petroleum consumption. It would feed one medium-sized refinery. Chevron estimates its investment at $7 billion, which will be deployed in modular increments as Chevron probes the problems, costs and market prospects.

Exxon had estimated that U.S. synthetic fuel capacity, including shale and coal, could reach 700,000 BPD by 1990, 4-6 million by 2000, and 15 million by 2015, neglecting limitations imposed by capital investment costs and water restrictions, as well as by infrastructure problems. The 4-6 million level is significant because it would replace U.S. oil imports; at 15 million BPD (or probably more by 2015), synthetics could supply all U.S. petroleum consumption. But at a level of only about 2 million BPD, water availability is expected to become serious, while the amount of solid material moved would equal constructing a new Panama Canal each year. Many have speculated that the requirement for draglines and other mining and earth-moving equipment may exceed the world's capability, triggering off undesirable price rises.

With Exxon's exit from current operations and general decline in activity by Occidental and others, forecasted goals will doubtless not be met. It remains to be seen whether financially independent operations such as Union Oil and Standard of California (Chevron) proceed apace and whether the U.S. Synthetic Fuels Corporation is able to maintain a good level of government-assisted activity.

Cryogenic Fuels — Cryogenic hydrogen and cryogenic methane (liquid natural gas) have both been discussed briefly in the preceding Board Room Briefing and will be covered more extensively in the body of this report, as well as in Volume 2. At this point a few particulars are added to the foregoing BRB comments.

At today's production costs, cryogenic fuels are generally regarded as becoming competitive when petroleum reaches much higher prices. In many respects, that concept is valid. Industrial hydrogen is generally an expensive commodity today and the technological bases for producing hydrogen do not appear to offer much economic improvement. Hydrogen can be produced from water by heat alone, but at high temperatures. At room temperatures, it can be produced from water by electricity alone. Both processes are currently expensive. There are literally hundreds of electrochemical, thermochemical (and photochemical) processes in between these two extremes, many of which are being explored. But the laws of thermodynamics and atomic bonding suggest no singularly low-cost prospects. Low-cost hydrogen is probably dependent on low-cost electricity.

Hydrogen is produced commonly as a byproduct and is used extensively in modern oil refinery operations. In fact, hydrogen is at a premium in refineries and is almost certain to become more valuable in processing petroleum and all types of synthetics. Many have remarked that, if hydrogen should become cheaper, it would be used better in processing and upgrading other fuels than as a fuel itself. By contrast, some envision a world-wide "hydrogen economy," in which hydrogen is used universally as the primary power in homes, in industry and ground transportation, and in air transport. The technical pieces fit remarkably well and show advantages over electricity; costs are dependent on local costs of primary power.

Hydrogen can also be produced from other hydrocarbons such as natural gas and coal (as it is from petroleum in refineries). The simplest process of all derives from natural gas because methane contains the most hydrogen atoms per unit weight and its molecular structure is simplest. But natural gas is itself an attractive fuel and, under present institutional conditions in the U.S., is not as readily or economically available as a feedstock as its chemistry would suggest.

This report concludes that limitation of U.S. natural gas is almost entirely due to historical and institutional restrictions, regulations, taxes and the like. If U.S. restrictions against production and use of natural gas were removed, including but not restricted to price controls, it is the author's belief that the entire U.S. energy economy would be restructured. Probably a minor consequence of this restructuring would be that hydrogen could then be produced from natural gas considerably cheaper than from any other source (although the methane would be still cheaper than hydrogen produced from it).

Most U.S. studies of methane and hydrogen costs are based on their production from coal. That is the pragmatic approach in the U.S. today, although other nations use different cost accounting. In the typical U.S. economic study, both methane and hydrogen produced from coal come out more expensive than do synthetic liquids.

But a proposal was made in late 1980 to the DOE for supplying 200 tons per day of liquid hydrogen to Los Angeles Airport at a price lower per Btu than current jet fuel. That proposal also included aircraft modifications and operations to consume the fuel on a flight-test operational basis. The proposal was rejected because the prevailing Congressional and DOE policy was to encourage alcohol and other more immediately-applicable fuels.

But, significantly, the proposal was headed by the subsidiary of a California utility holding company. By selling excess by-product electricity at its favorable prevailing rate to the local utility at the production site, the proposal was able to deliver LH_2 at very attractive prices. This proposal's economic framework was endorsed by the California Public Utility Commission. While it may represent a special case wherever electrical rates are high, the significant fact is that the entire proposal

was essentially state-of-the-art and economically competitive.

What may be most significant is the fact that specific contemporary industrial and economic conditions appeared capable of producing hydrogen at competitive prices. This suggests the possibility that parallel conditions might create attractive economic climates for other synthetics or fuel-production processes. We should not assume that our economic data base will remain fixed. Developments in economics and industrial accounting may be more important than in technology. Government regulations and restrictions, rulings of bodies like utility commissions, and taxes at all levels, may be most influential of all. A nation which rates nuclear-produced or other electricity at a very low cost, for example, could produce hydrogen at a low cost.

Both LH_2 and LCH_4 (liquid hydrogen and liquid methane) weigh less per Btu than kerosene but, because of their volume and low temperatures, would require commercial aircraft with large, insulated tanks. In the engine, both fuels burn more cleanly than kerosene and would be expected to reduce maintenance, improve performance, and extend engine life. Either can be used effectively in existing engines with modified fuel systems; they would no doubt lead to more efficient engines, if designed initially for cryogenic fuels.

LH_2 at competitive prices would offer both performance and economic advantages over kerosene; it is the only fuel capable of providing an airplane with non-refueled, semi-global range with today's aircraft performance technology. Liquid methane, LCH_4, represents a fair straddle between LH_2 and kerosene. It has less energy per pound than LH_2, but more energy per cubic foot. It must be liquefied to be useful in aircraft, but its liquefaction temperature is −259°F, rather than −423°F. Use of both fuels may be inhibited by the "Hindenberg Syndrome," the fear of crash fire. Practically, tests indicate that survivors in a LH_2-fueled aircraft should have much better fire protection than with jet fuel. It is not so clear whether a cloud from a massive hydrogen spill would threaten the airport terminal or other surroundings. The fire-safety characteristics of LCH_4 in large quantities do not appear as favorable as LH_2, either for passengers or for the neighborhood.

Any cryogenic aircraft fuel introduces the need for liquefaction, supply, and reliquefaction of boiloff at the airport. At an airport such as O'Hare, the liquefaction system was estimated to cost over a billion dollars at 1978 prices. If driven by nuclear power, liquefaction at O'Hare would require a larger nuclear plant than any built to date. There is some promise that magnetic liquefaction could reduce both the economic and energy costs of liquefying hydrogen by up to 40%. That process is in the laboratory stage.

These types of infrastructure problems will maintain strong economic resistance to the introduction of airline-type cryogenic operations.

Demand-Side Options

The 1980 U.S. jet fuel bill was $11 billion, while airline losses posted for the year were approximately $200 million. A 2% decrease in fuel costs therefore would have erased the airline financial loss and fuel costs are seen to play an important role in the industry. Airlines can selectively reduce demand for fuel by cancelling routes, by consolidating flights, and by installing more seats per aircraft, all of which may also depress traffic. The more attractive avenue for air carriers is to conserve fuel while providing comparable service. Fortunately, some means for conserving fuel can be accomplished while service is even improved.

Mainly by using larger aircraft, reducing cruise speeds, flying at more efficient altitudes, corrective maintenance, grounding inefficient aircraft, and the three methods mentioned above, airlines in the U.S. increased their fuel efficiency from 14.8 passenger-miles per gallon of fuel burned in 1973 to 22.2 in 1979, a 50% improvement. It is obvious that, without having taken these steps, and with all other factors constant, the 1980 airline losses would have been more than twenty times greater. During that same period, the airlines and FAA also jointly improved gate-hold and airborne flow control procedures, traffic control, taxiing procedures, training methods and airport operations.

System Improvements — Many aviation operating units and study organizations have directed strong attention toward methods for conserving fuel. Under contract to the DOE, The Aerospace Corporation in 1978 published a study of "47 Strategies"(1-10) for aviation fuel conservation. By the time of publication, many of those strategies had already been applied in part or in total. After the 1979 sharp rise in fuel prices, Fig. 1-1, more of the strategies became economically attractive than beforehand. Some tests showed that standard aircraft cockpit instrumentation produced data scatter of about 3% but, through multiregression analyses, airlines were able to identify means for conserving fuel quantities of the order of one-half percent. Some of these elusive procedures have been found cost-effective.

Most of these avenues have now been completely exploited. For example, flying some of the more efficient aircraft at still slower speeds would actually increase fuel consumption per passenger-mile, while increasing other costs. Airlines are devising increasingly sophisticated procedures for determining their least-cost options. There is still some potential for improvement in airline maintenance, though small, and in procedures which will require further joint airline-FAA action: improved flight planning and preparation, loading and taxiing, flight procedures and Air Traffic Control (ATC) procedures. Most of these are being pursued vigorously, as far as existing equipment will permit. The potential saving remaining with present equipment is about 5%.

With addition of new ATC automation and flight-management equipment, there is potential for additional system savings up to 10% in fuel due to remaining holdings, delays, reroutings and other operating inefficiencies. In general, airborne equipment capability outpaces the ground system because of the size of the investment required to make system-wide changes, as well as conventional federal budgetary constraints.

A very attractive opportunity exists for saving the order of $300 million in fuel costs per year within this 10% total by improving the existing aviation weather measurement and forecasting system, which lags far behind the technology and efficiency of both present aircraft and the ATC system. This situation exists because aviation weather is derived from the same data base and essentially by the same analyses used by the National Weather Service for agriculture and all other national needs. By law, the NWS alone is authorized to record weather and prepare forecasts for civilian purposes. Since upper-air observations are taken and forecasts are made only twice a day, airline flights planned with stale data not only operate in unfavorable wind and temperature conditions along their routes, they encounter unnecessary traffic diversions and delays because of obsolete weather information. They may also confront

unexpected bad weather.

An airline can find that all the fuel savings it achieved through installing sophisticated data-management systems, optimizing flight planning and procedures, maintaining the airplane at peak efficiency, and so on, can disappear in a few minutes of unscheduled holding at low altitude, or in an unexpected headwind.

About 3% more direct fuel efficiency can be gained nationwide with reliable wind and altitude data, using off-the-shelf equipment, costing about $1 million in capital equipment and an initial annual expense estimated at about $600,000. The total savings realized should be much greater due to reduced delays and improved capacity of the ATC system. Unfortunately, neither the NWS nor the FAA holds direct responsibility for the entire air weather system or its performance, while the budgets for both are fully committed with immediate responsibilities. But this potential is well known at working levels in FAA, NWS and NASA at the present, while NASA is conducting a comprehensive data analysis to determine its cost effectiveness. It is hoped that constantly-increasing budgetary pressures will not prevent this highly valuable option from being investigated and adopted.

Aircraft Improvement Potential — Aside from the economy of operating existing aircraft more efficiently within an improved system, there is, of course, the potential for developing more fuel-efficient aircraft. Present aircraft powered with low-bypass-ratio turbofans can be improved up to 20% by installing high-bypass turbofans. Each airline must consider whether this approach is cost-effective for its particular circumstances. Different variations of this approach are being pursued in the market. Improvement beyond 20% requires a new airframe, that is, a completely new airplane.

Recently, aircraft synthesis and optimization computer models have been directed toward minimum system costs, or maximum return on investment, rather than toward the traditional minimum aircraft purchase price. This approach applies more emphasis to fuel economy. As a result, while new aircraft such as the Boeing 757 and 767 may look much the same, they will operate somewhat differently. For example, they will have larger wing areas and fly at higher altitudes, even at short ranges. As a sidelight, they will then also be more susceptible to fuel penalties if operated in off-design conditions.

Manufacturers, research organizations, study groups and others, all are in good agreement that by 1990, new aircraft can realize a fuel improvement over today's low-bypass-ratio engined aircraft (727s, 737s and DC-9s) of 45-50%. There is a minority opinion that the following decade, 1990-2000 can expect another 40-50% improvement in fuel burn. A majority believe that the 1990-2000 improvement will not be so great.

As has been seen, these sizeable percentage improvements in aviation fuel conservation do not amount to much on a scale of national energy. On the other hand, they are vitally important to airlines. In the past, airline re-equipment has usually been based on competitive customer service and appeal, or on rising maintenance costs with old equipment. In the future, airlines may face a perpetual tension between fuel costs on the one hand and capital equipment costs on the other. The leverage appears to be increasing; airlines which encounter cash-flow problems due to fuel costs, may not be able to buy the new aircraft they need to reduce fuel costs and remain competitive.

Fuel Supply Disruption

U.S. petroleum imports dropped 42% from the peak in 1977 to November, 1981, but they are still more than 32% of the U.S. petroleum used. A Senate report of December 1980 [11] states, "The United States and our allies are likely to experience at least two more decades of vulnerability to supply disruptions, political manipulations of supplies, and periods of panic buying on the spot market." Some observers are more alarmed than this and criticize the lack of a U.S. emergency energy plan. Others think the influence of OPEC is rapidly waning and that foreign disruptions will no longer cause concern after about ten years. The Senate report appears reasonable, particularly when considering the continuing economic vulnerability of U.S. allies and the Western World in general.

There appear to be no political analysts who are optimistic about the long-term view for foreign crude import stability. On the contrary, while acknowledging the immediate state of relative price stability, foreign affairs analysts state that future disruptions are not merely likely, they are probable. "Probable" means three serious crude-oil import supply disruptions may occur in any ten-year period and one such disruption is almost sure to occur in five years. One office has studied about thirty scenarios for Mideast instability. Although they remark that many of these may appear implausible, the aggregate is so large they conclude one is almost certain to occur in a five-year period. Ironically, it may be one that they have not considered.

Depending on views about the supply/demand balance, opinions vary as to how serious a disruption will be. Some expect that the effects will be felt less than in 1973-74 or in the Iranian-involved crises. Others expect the crude disruption will be severe and that prices will double again. The net effect will be strongly dependent, not only on the depth of a disruption, but on the rapidity with which it occurs.

The U.S. oil refining and supply system is largely a flow-through system, with static stocks used essentially to accommodate fluctuations in the flows. That is, except for privately-held static stock, there is not a great deal of reserve in the system which can be drawn down in emergency. Some private storage capacity and extra stock has been established since the two major price rises, but these are not great enough to relieve the national situation. In general, U.S. internal operation during a major disruption will be dependent on the Strategic Petroleum Reserves (SPR) and, of course, on ad hoc arrangements that many users and suppliers may make.

The SPR was being filled at a rather slow rate, averaging about 100,000 BPD until April, 1981, when a purchase agreement with Mexico led to achieving its maximum fill rate of about 300,000 BPD. A U.S. emergency policy has not been established by the current administration, but the National Petroleum Council (NPC), which advises the Secretary of Energy, recommends that the SPR should not be drawn down below 200 million barrels during a disruption emergency. [8] That amount of bedrock reserve should be held for unanticipated critical emergencies. The SPR will not exceed 200 million barrels until the middle of 1982; it will not reach a significant level until 1986-88. At that point, it would be able to supply about 3 million BPD for four months, optimistically about the rate of foreign oil we may be importing at that time.

At that point the U.S. is not off the hook, because its agreements through the International Energy Agency (IEA) require

sharing stocks with its allies in Europe and Japan in case of serious disruption. Because of these commitments and plain international trade pragmatism, about half of the foreign affairs analysts conclude the expected disruption in Mideast oil will lead to another doubling of crude oil prices.

In its report to the Secretary of Energy, the NPC reviewed all elements of U.S. emergency energy consumption, including the participation of aviation. It observed that aviation is an important function and that it does not use a large percentage of the U.S. total energy. Other than sharing in the national encouragement to conserve energy, the NPC does not recommend any attention toward aviation short of a moderate or greater disruption (say, 3 million BPD disruption expected to last at least 3 months).

The NPC noted that aviation has already taken vigorous and sophisticated steps toward fuel conservation and that it is expected to continue to do so without any remonstration. At higher levels of import disruption, the NPC recommends that airlines be urged to increase their load factors from the normal 60% up to the 70-75% range. General Aviation is judged to be a small energy consumer and important enough to industrial management and general mobility of the economy such that no regulations or special actions will be applied.

It is noteworthy that, for all anticipated levels of crude oil import disruptions, the NPC recommends no government interference in either prices or allocations, unless major national dislocations occur. They expect that buyer-seller relationships will govern allocations. It is debatable whether the Administration or the Congress will follow these recommendations in ensuing legislation, or at the time the first emergency arises.

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Chapter 2

World and Long-Term Energy View

With energy prices and supply/demand balances changing so erratically during the past several years, it is not surprising that both the view of the current situation and the outlook for the future have changed rapidly. Many observers have spoken of "the energy bridge" and have used a bridge as an analogy to our transition out of the present energy situation. In November, 1980, for example, C. C. Garvin, Jr., Chairman of Exxon, spoke to the University Club in New York,[2-1] saying, "The near-term challenge, essentially, is to construct an energy bridge to the twenty-first century. It will have to be a bridge built largely of conventional materials — the traditional non-renewable fossil fuels — but it will employ to an increasing extent techniques that are *not* conventional."

As mentioned early in Chapter 1, the most authoritative and certainly the most extensive world-wide, long-term analysis of energy transition was made by the International Institute of Applied Systems Analysis (IIASA) over a five-year period at Laxenburg, Austria. Twenty countries participated, with the National Academy of the U.S. supplying 30% of the funds, the National Academy of the USSR supplying 30%, while the remaining 40% was shared among the others, which included representation from OECD, OPEC, and LDCs, (Less Developed Countries). This chapter is largely concerned with the IIASA findings.

By inserting this chapter here, the sequence is different from the EXECUTIVE SUMMARY, where aviation fuel was reviewed first. There it was desirable to draw a picture of the aviation situation before launching into the somewhat remote, long-term world situation. But with that brief foundation established, here it is believed best to lay out the long-term base first, so that the remainder of this report can proceed uninterrupted through matters more directly concerned with aviation.

Board Room Briefing No. 2.

1. In any forecast involving human activities over a period of fifteen years or so, completely unanticipated events are likely to occur which will affect the outcome of the forecast more than any of the predictable inputs.

2. Whatever the undiscovered stores of world petroleum resources, they cannot supply world energy demands indefinitely. Other energy sources must provide major contributions. No single source can supply most of humanity's needs; several energy sources and forms will replace petroleum over the long run.

3. Transition into an energy system without major reliance on petroleum will take more than fifty years, due to capital expenditure and sociological difficulties. Hydrocarbon fuels such as coal will continue to make major contributions. Although fossil fuels will eventually become minor components, they may never totally disappear from the scene.

4. The major world energy problem today is the demand for liquid fuels. Future ***long-term*** demand for liquid fuels will not decrease; because of the needs of Less Developed Countries (LDCs), the press for liquid fuels will probably become more critical with time.

5. High costs of capital equipment needed for electrical distribution and storage indicate that little of the LDC energy needs will be met with electricity. LDC and transportation requirements will maintain and increase the demand for liquid fuels.

6. Because of this need for liquid fuels and dependence on the liquid-fuel distribution system, in the long run, world coal and even nuclear power should be used more to produce liquid fuels than for heat or electricity.

7. *In the world liquid-fuel distribution system*, petroleum will probably be replaced gradually by methanol and eventually by hydrogen. Hydrogen should become the world's dominant liquid fuel by Year 2100. Hydrogen could emerge sooner, depending on a variety of events.

8. Worldwide, the capital costs of energy will increase substantially. By 2000, the industrial nations will spend about 100% more in direct capital funds per unit of energy. About 250% more will be spent per unit of energy in infrastructure and environmental protection. The capital costs of energy for LDCs will rise four times as fast as for industrial nations (because their outlays are so low now).

9. IIASA concludes that future world energy needs can be met from the standpoint of both technology and economics, but solution will require every feasible energy option considered. IIASA did not address the purely sociological or political problems, or anomalies in world cost/price relationships, such as in petroleum today. IIASA considers these problems to be formidable and not necessarily solvable in today's international political structure. Inevitably, they may produce much world suffering and death in the future.

10. Man's activities will double the amount of carbon dioxide (CO_2) in the world's atmosphere by Year 2030. It is not yet known what the effects may be, or to whom. By the time these answers are determined with assurance, it may be too late for remedial steps. Many believe the process will be irreversible by the time the effects can be determined with any assurance.

The IIASA study is already somewhat a victim of its own forecasting. Who would have expected that one of the proverbial erratic events might occur before the end of the first year?

But, in fact, it has. No one conceived that the United States, the world's largest energy user, or the rest of the world could achieve so much conservation and reduce the demand for energy so drastically before the end of 1981. This trend began slowly in 1973-74 and was developing at the time the IIASA report was being written. But its true nature could not be discerned as recently as a year ago. We still may not appreciate its full effect.

Today, an IIASA reassessment of its analyses and conclusions would almost certainly yield more optimistic results. Over a period of 20, 40 or 70 years, a small difference in cumulative percentage trend changes the results dramatically. (The classical rule of thumb is that 1% doubles the result in 72 years). Between 1979 and 1981 the world reduced its petroleum demand by almost 5 million barrels per day, or over 9%.[2-2,2-3] While this trend will not be sustained, it suggests a reevaluation of all forecasts made before the middle of 1981 and a close examination of the assumptions in forecasts made later.

This report, then, is being written at a time of double, triple or multiple uncertainty. It can only be hoped that trends in the near future will be mild, or will cancel each other enough so that this report can have a reasonably useful life.

The IIASA Study

IIASA is a non-governmental research institution founded in October, 1972 by the academies of science and equivalent scientific organizations of twelve nations from both East and West. Its Energy Systems Program was begun in June, 1973, with approximately 150 specialists and analysts from twenty nations, which represented all components of global interests. Its Phase 1 Report, ***Energy in a Finite World***, was released in early 1981 in two volumes, the first being a summary of 225 pages.

In the Preface, it states, "IIASA is a small research institution, and the group studying the energy problem was relatively small. We therefore did not judge it useful to compete with the energy research of larger national and regional groups. Our intent was to complement their work by providing a long-range, global view of the problems facing civilization. In particular, we aimed for complementarity with the Workshop on Alternative Energy Systems (WAES).[2-4] Similarly, our thinking was stimulated by the World Energy Conferences of Detroit (1974) and of Istanbul (1977) and by our contacts with major groups in the energy field such as those of the Academy of Sciences of the Soviet Union and the European Community."

IIASA points out that a concept of "The Energy Crisis" is innacurate, or at least misleading. After a crisis, recovery is expected and a previous life can be resumed. The world's concern with energy is chronic, will continue indefinitely, and the world must learn to live with it. As we have already seen, the situation may take turns for the better or worse as history unfolds.

IIASA considered the world energy picture first by checking for a solution in a fifty-year period, that is, by 2030. There were several reasons for this selected goal. First, although the world's population is in its steepest growth rate during the study period, they hope that it will have essentially stabilized by that time. "Quite simply, in a finite world, exponential growth must ultimately stop."[1-6] The converse is also true; if the world's population is not stabilized by 2030, transition in world energy will be more traumatic than expected.

Second, fifty years represents two generations, both in human experience and in capital equipment. Transition in major capital equipment is slow; therefore, IIASA concluded that two generations would be required to bring really different equipment concepts to bear. Similarly, some of our current problems, such as resistance against nuclear development and expanded use of coal, are sociological. It may be expected that resistance against hydroelectric power (one of the most environmentally disturbing power systems), solar power, wind power, oil shale and nuclear fusion (which may be as difficult radioactively as fission) will have to go through sociological evolution before fully accepted, or before compromises can be developed.

Lastly, Europe experienced a serious firewood crisis during the middle part of the nineteenth century. If coal had not been available at that time, the industrial revolution would have been significantly delayed. About fifty years expired before the use of coal increased from 20% of total energy to 50%. (Owen Phillips of Johns Hopkins has also pointed out a wood crisis in England near the end of Queen Elizabeth's reign).[2-5]

IIASA analyzed statistically the history of five major energy resources in the U.S. — wood, coal, oil, natural gas, and nuclear energy and found remarkable similarity in their patterns. On the basis of trend, they conclude, for example, that solar power will penetrate only 7% by 2030, which they remark is probably much less than many people would hope. On the other hand, they point out that solar contribution would then be equivalent to 22 million barrels of oil per day, the total 1975 production capacity of the Middle East and North Africa combined.

One of the shocks one experiences over and over again in considering energy needs and comparisons is the fact that their sizes are often incomprehensible. We apparently can conceive distances of light-years in space with little difficulty, but there seems to be no way to ge a mental feel for the amount of oil the U.S. uses each day, for example.

So, in terms of the energy bridge, IIASA figuratively regarded its terminus as being obscured by at least three fog banks (three 15-year intervals of unforeseeable developments in the 50-year period). As shown in Fig. 2-1, it might be said that they fired a 50-year test shot out from the petroleum base. They did not score a hit; they got a splash. Their analysis showed it was highly unlikely that the capital investment for a significant transition from petroleum could be laid down within fifty years. On a more subjective basis, they also concluded that sociological resistance would not permit technological progress at the rate required to reach a firm base in the fifty-year period. They concluded that the possibilities for both were fairly good by seventy years, in 2050. But that meant adding almost two more cycles of unforecastable developments (fog).

Even at the end of the seventy-year transition period, it was evident to them that the result was by no means as conclusive as many had hoped and expected. The whole gamut of energy sources and forms will be required to meet the world's projected needs, exploiting each application where it is economically superior. In 2050 the world will still be using considerable fossil hydrocarbon energy, especially coal.

IIASA did not entirely share the author's enthusiasm for natural gas, partially because, while the World Energy Conference reported an encouraging outlook in its chapter on gas, it did not include this optimism in its summary for the Istanbul (1977) session. The Munich (1980) session is still cautious. In part it states, "Compared with the long history of the use of oil, the gaseous hydrocarbons have only come into use recently. The intensive utilization of deposits containing solely natural gas has been only taken (sic) place in the last few decades, starting out with the deposits that lie directly adjacent to consumer centres. Even now, associated gas arising during recovery of oil remains totally unused in some cases. . . . During the last 20 years, the utilization of natural gas has made an astounding expansion, and without doubt even today has not reached its peak. The relationship of proved reserves to current production is nearly 50:1

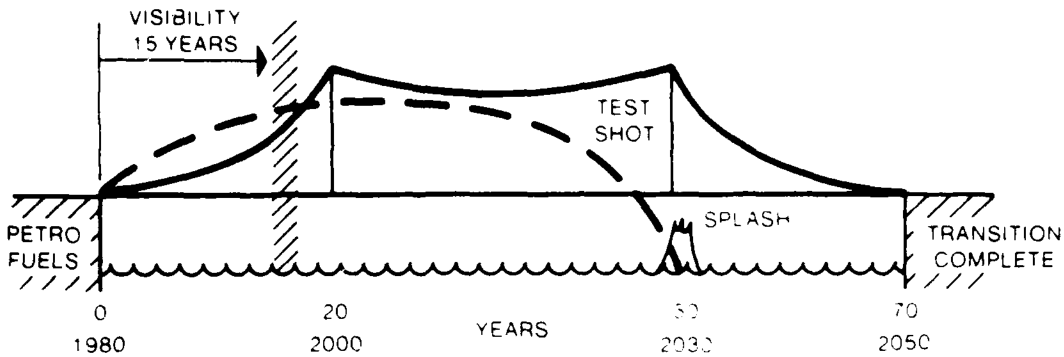

Figure 2 1
The Transition Bridge

and is thus considered more favorable than in the case of oil." Gas then and now, is regarded by many as an ineligible player.

IIASA Conclusions

"The 'energy problem,' viewed with a sufficiently long-term and global perspective, is not so much a general energy problem: Strictly speaking it is a liquid-fuels problem — or, more precisely, an oil problem. Thus, the problems of balancing global supply and demand for liquid fuels pose a unique challenge. In our scenario writing we restricted the use of liquid fuels to their most essential purposes only — that is, as transportation fuels and as feedstocks for the chemical industry. . . . Nevertheless . . . in spite of vigorous measures to conserve liquid fuels, these fuels still represent the major component of energy use in the scenarios in 2030."

In his verbal presentation at the Eighth Energy Technology Conference, March 11, 1981 in Washington, Professor Wolf Häfele, Deputy Director of IIASA and Program Leader of the Energy Systems Program, commented that if the industrial nations gave the LDCs enough nuclear plants for the energy they will need, neither the LDCs nor their benefactors could afford to supply the electrical distribution and storage systems that would also be required. Similarly, if the price of photoelectric cells reduces to zero, neither LDCs nor industrial nations would be able to afford the concrete, steel and other equipment to install and control them in the quantities required. The only prospect for distributing energy in the quantities required appears to be the liquid-fuel distribution system, expanded and evolved as will be needed.

IIASA noted that, "Over the previous twenty-five years, global primary energy demand has grown at a surprisingly consistent 4.8 percent per year. . . . by 2037, the growth in energy use in that year alone would exceed the total amount of energy consumed in 1975. The question then is not whether energy growth will slow down, but when, at what level, and in which world regions?" IIASA analyzed high and low scenarios for economic growth, as well as possible energy consumption trends for various world regions. "It is possible to design scenarios of extreme energy conservation. Balancing supply and demand can be achieved either by going to the extreme on the supply side, which means facing all the troubles of advanced supply, or by going to the extreme on the demand side, which means encountering all the hardships of enhanced energy-saving measures."

IIASA explored this issue by examining the extremely low case of energy demands proposed by Dr. Umberto Colombo of the Club of Rome in 1978. Essentially, he assumed the world could survive in 2030 on double the energy it used in 1975. With world population doubled in that period, consumption per capita would remain the same, but the distribution among world regions would change, with LDCs getting a much larger share. This would naturally mean that the per-capita consumption in industrial countries would decline substantially. And the fifty-year period would be critical; if the world could accept that adjustment, subsequent periods would be fairly well stabilized. The industrial decreases in energy use had to be consistent with an assumed 2% per year growth in GDP (Gross Domestic Product)

It appeared that these goals could be met only by, ". . drastic changes in economic conditions and lifestyles, in addition to technological improvement: There, (energy for) the manufacturing and basic materials sectors would go down, while the services sector and the share of machinery and equipment within the manufacturing industry would go up. Intercity transportation would remain at 1975 levels, despite the assumed 2 percent per year GDP growth. For Region I (North America), bus service would double and train services quadruple, whereas air traffic service would be reduced." A gloomy prospect for aviation, one that IIASA did not consider feasible.

In viewing North America, IIASA concluded its future will be, ". . . dominated by three considerations — a post industrial, mature economy, 'slowdown;' substantial energy savings because of technological advances and some restructuring of economic activities (but they could not foresee how much conservation could occur so soon); and a rapid buildup of coal liquefaction industry to replace domestic and imported oil. None of these changes, except possibly the last, is expected to produce profound or sweeping changes in lifestyles of North Americans."

As a matter of interest, IIASA expects North American real growth to drop from 3% to 1-to-2% after Year 2015 and per capita GNP to be "somewhat lower." "People's traveling and other energy-consuming activities are expected to saturate, meaning that aggregate growth will be slower . . . They would still commute to jobs, take vacations, drive automobiles. An all-bicycle or an all-high-rise apartment future is not likely "

"The environmental, labor, water and transportation issues surrounding coal production in the United States cast some doubt about rapid coal production increases. Yet the liquid fuel demands seem irreducible, and the coal resource is available. The world would need the coal-based liquid fuel supply that Region I could export . . . The major global alternative to coal liquids would seem to be shale oil — also an export from this region . . . the dominant sources (of primary energy use)

would be nuclear energy and coal based on the aggregate of supply constraints and market restrictions With greater flexibility in these constraints, a conceivable big energy source for the future in Region 1 could well be natural gas."

IIASA was more pessimistic about the future of petroleum than is the author and statements made by U.S. oil industry representatives since the IIASA report, which will be covered later in Chapter 3. IIASA concludes, " known reserves of conventional oil in the world's market economies are almost exhausted by the year 2010. This is essentially the man in the street's perception of the energy situation, and in this respect, he is correct. We therefore had to search for new reserves of conventional oil, Mexico being a case in point. But in our scenarios we accounted for all the Mexicos to come, and still oil production did not go above the level of 25 million barrels per day (outside Region VI, Middle East North Africa). We were then forced to go to unconventional oil sources, such as the Athabaska tar sands in Canada and the Orinoco heavy crude oils in Latin America, recognizing the new geopolitical patterns that would develop when the unconventional oils began to play such a role."

"But even turning to unconventional oil sources was not enough, and sometime around the year 2000, large-scale coal liquefaction would become a necessity, yielding a total oil production outside Region IV (Latin America) that would still not meet the minimum demand for liquid fuels required for essential uses."

This conclusion might be modified either by the now-recognized world improvements in conservation, or by accelerated success in conventional oil production which is expected by the author. A world-scale upsurge in natural gas production and consumption could affect this situation dramatically.

World Energy Conference (WEC)

WEC Organization — The WEC is undoubtedly the most universal and prestigious energy organization in the world. It was organized in 1924 and has 76 National Committees made up of the outstanding energy experts from its member countries. Although not a part of the United Nations structure, it functions as the UN body for energy assessment and forecasting on the senior level. It is chartered to promote the peaceful use of energy by evaluating resources, considering energy consumption and economics, publishing its findings, and holding triennial meetings for review and discussion. As has been noted earlier, its past three meetings were held in Detroit (1974), Istanbul (1978), and Munich (1980).

While its membership assures access to the best energy data available, its size and schedule inherently handicap the operation of WEC. Information is gathered through national committees, as well as from non-member nations, typically through questionnaires in order to maintain consistency and comparability; no mean task. Even within countries as developed as the U.S., maintaining consistency of definitions and assumptions in recording inventories or in forecasting discoveries can be precarious.

In its reports, the WEC advises that the quality of information varies widely among members, while geological exploration levels in world regions are tremendously different. But they apply great professional effort to data analysis and, for assemblage at the global level, the WEC information is doubtless the most comprehensive there is. It is usually the base reference selected for studies concerned with global energy matters. However, particularly for U.S. users, other analyses which employ the WEC information may be more applicable and timely.

For those concerned more with North America or the United States than with the world picture, the WEC material may be best used as an oblique reference. Its U.S. members, in fact, are actively engaged in day-to-day energy matters. As oil company chairmen, they frequently report to their stock holders and make speeches to interested groups such as brokers and economists. The academic members publish frequently; government employees issue regular reports and are available for consultation. The U.S. Geological Survey also performs world-wide assessments in which they use WEC data or information from many of the same sources as WEC. The WEC material may serve best for Americans, therefore, as a long-term or moving-average assessment. It cannot respond rapidly to current trends and developments.

WEC Report — In that context, results from the WEC 1980 Conference, ***Survey of Energy Resources***, are briefly summarized. The document itself frankly discusses limitations in its processes, such as using bar graphs to show responses, and lack of response, from various world areas and nations on different reporting matters.

Of the world's total 383 PJ (perra-Joules, or 10^{15}J) in estimated available **conventional** energy resources, 33.4 PJ, or about 11.5% is proved and the remainder is estimated, yet to be discovered. Of the total, almost 83% is in coal, 16% is other hydrocarbons, and just over 1% is in uranium.

"In the last 20 years the majority of estimates made for the total quantity of oil recoverable ('ultimate recovery') lie in the range 240-360 x 10^9 tons. The figure of 354 x 10^9 tons, excluding NGL (natural gas liquids), for 'ultimate recovery' quoted in this report also lies within this range, and can be considered conservative in comparison with some of the estimates." Up to the end of 1978, approximately 15% of this total had been recovered. In natural gas, 9% of the estimated ultimate recoverable resource (293 x 10^{12} m^3) had been produced by the end of 1978.

"Without doubt, the ultimate potential of the oil shales and bituminous sands is very high, but it is currently not possible to estimate how significant they will become in the future in helping to satisfy a proportion of the world primary energy needs. It depends on what advances can be made in the development of suitable production and treatment methods. The experience gained up till now is not sufficient to be able to give an accurate statement on the possibility to develop and improve the presently known techniques, and certainly not sufficient to be able to indicate the actual costs that can be expected in manufacturing marketable products."

This assessment seems rather cautious in view of the extensive and vigorous moves that U.S. major companies were making in oil shale at the time of the WEC report. On the other hand, it may mean that Exxon's oil shale cancellation is based on fundamental factors and it is sobering to see how those efforts appear to observers viewing the picture from the global plane.

WEC concludes that reserves of oil shale and sands are greater than reserves of conventional oil, and that the reported estimates are conservative. Also, "One could expect that the yearly world gas production will continue to increase. Just as in the case of oil, consideration of the production of natural gas in the different country groups shows clearly that future developments depend on political decisions. Mainly the OPEC countries, while possessing a reserve situation that is good to very good and a comparatively small production, are technically able to make a considerable increase in production capacity in the short to middle term."

"Since 1973/74, pricing of the world oil market has been uncertain as it has been mainly politically determined. Therefore, it is hardly possible to estimate the future development of the oil market prices . . . The degree of exploration on hydrocarbons varies considerably from region to region. North America stands out far above all the other countries: in the Western World approximately 90% of the total drilling activity made up to now has taken place in only 23% of the prospective areas."

WEC 1980 Meeting — The United States National Committee reported[..] some interesting observations from the 11th World Energy Conference (over 4000 conferees from 82 countries), held in Munich from September 8 through 22, 1981:

1. Conventional oil supplies will decrease from the 1900s onward. Natural gas production will follow the same pattern.

2. One of the decisive energy factors **worldwide** will be the development of nuclear power in the industrialized nations.

3. Coal will be increasingly important, but its production, transportation and handling problems will be formidable.

4. World banking will be able to finance energy developments, provided national policies reduce consumption and permit formation of large amounts of risk capital.

5. Solar low-temperature applications will increase but high-temperature applications will require much more R&D.

6. Geothermal sources will increase in importance, but contributions from other renewable sources will be modest.

7. Other countries are telling the U.S. to do the things we think we should be doing. Third World countries particularly urge the U.S. to accelerate domestic coal and nuclear development, in order to leave more of the world's finite oil supplies for them.

8. "Speaker after speaker from nation after nation — industrialized as well as developing — underlined the central, keystone role which nuclear power must play if the world is to have an energy resource base adequate to support all its people at acceptable living standards."

Even the USSR Minister of Power and Electrification expressed the opinion that opposition to nuclear power in certain western countries is transitory and will disappear when the need for nuclear power becomes unmistakably clear.

Representatives from industrialized nations were surprised at the endorsement nuclear power received from many Third World and oil-exporting countries. Oil-exporting countries want to development oil-independent economies with nuclear and solar energy before the oil market subsides.

9. Synthetic investment costs will be high, reported by Fred L. Hartley, Chairman of Union Oil and Chairman of the American Petroleum Institute. He presented investment costs which now look moderate ($40,000 capital investment per daily barrel of oil production, vs. $100,000 being quoted now by project managers). But a shale plant will deliver a constant production rate, rather than declining as do oil wells, and is considered a better hedge against inflation.

10. Renewables (solar, wind, biomass) should play a vital role in increasing energy per capita in Third World countries. But arguments many Americans have made about the need to put renewables in economic perspective, were echoed by Europeans, Russians, Chinese and many LDC representatives.

11. Countries must discuss and solve public understanding of nuclear power as a safe, environmentally acceptable energy source. Dr. Peter von Siemens, the newly elected President of the WEC, called for a "trialogue" with the oil-producing countries, the industrial nations and the LDCs. Among other matters, they should cooperate toward solving nuclear proliferation and means to disconnect it from the nuclear fuel cycle and peaceful uses of the atom.

12. Dr. Klaus Knizia, president of West Germany's National Committee to WEC, responded to Chancellor Helmut Schmidt that engineers and scientists have been living up to their responsibilities in reporting on nuclear affairs and, " . . . it is the equally important responsibility of the politicians, the public and the news media to listen to the scientists and engineers, rather than to the opportunists." He also remarked, "The starving millions of people in the world face risks everyday that make the nightmares of some of us in the affluent societies pale into insignificance. Adequate energy is one means to reduce those risks for those millions, and we cannot fail them."

WAES Report — As noted earlier, the IIASA report intentionally avoided repeating other studies and, " . . . aimed for complementarity with the Workshop on Alternative Energy Systems (WAES)," which was completed at MIT in 1977.[24]

Depending on how one looks at the results, it is either encouraging or discouraging to consider the WAES report in the light of succeeding events. Encouraging because the picture has improved so much, discouraging to see how obsolete a highly expert and professional study can be rendered in such a short time.

In its introduction, one member of WAES concluded that world oil will, " . . . run short sooner than most people realize." The prediction was placed at around 1985-1995, as early as 1983. It should be noted that the conclusion was based on then current oil prices. While WAES concluded that oil production would fail to meet demand by 1985-1995 even with a 50% increase in energy prices, it is only fair to note that prices increased more than 100% since their report.

Some other conclusions from WAES are worth noting, either because as a U.S. view they differ somewhat from IIASA, or because they confirm and strengthen what otherwise might be considered a more foreign IIASA attitude. (Although the largest group of IIASA participants was from the U.S., the report's conclusions were written essentially by its director, Dr. Häfele).

WAES does not expect any of the solar energy forms to be significant before 2000. Since they were then only emerging, it was particularly difficult to estimate their costs or environmental effects. They noted that any energy source, to have a significant effect in the U.S., must be able to replace millions of barrels of oil per day. Large investments and long lead times will be needed for any energy developments.

All WAES supply/demand scenarios assumed much energy conservation. Electricity from nuclear fission must make a substantial contribution; fusion cannot be significant before 2000. Coal needs development, but should become a large segment of energy supply. "Natural gas reserves are large enough to meet projected demand provided the incentives are sufficient to encourage the development of extensive and costly intercontinental gas transportation systems." Oil sands, heavy oil and shale are likely to supply only small amounts before 2000.

"Other than hydroelectric power, renewable sources of energy (solar, wind power, wave power) are unlikely to contribute significant quantities of additional energy at global level although they could be important in particular areas."

The critical interdependence of nations requires unprecedented international collaboration, common purpose, and immediate action.

CONAES Report — The report of the Committee on Nuclear and Alternative Energy Sources (CONAES) of the U.S. National Academy of Sciences[27] was not available prior to completion of the IIASA report although, particularly since IIASA's Dr.

Häfele was from the German nuclear energy establishment, the two groups doubtless had good communication. Like IIASA, the CONAES study did not project energy supplies and demand, but explored scenarios of different levels.

Among other conclusions, CONAES noted that, while U.S. energy shortfall was in fluid fuels, most of the new options are in electrical power, which is only about 10% of U.S. energy end uses. The supply of fluid fuels was seen to become critical in the 1985-2000 period, acknowledging that forecasts could not be reliable. The future was considered largely unpredictable and therefore, the U.S. should develop a variety of options and "Should not become dependent on a monoculture, such as we had in oil."

The road the U.S. takes will be determined largely by political choices, guided by the type of society desired. A major conclusion of the study was that technical efficiency measures alone could reduce U.S. energy consumption by half.

The CONAES Solar Energy Resources Group concluded solar energy could contribute substantially to U.S. energy by 2010 with strong government support, but energy prices alone would not develop the solar market. If stimulated enough to make a sizeable contribution (15-20% of national energy consumption), the costs would be measured in trillions of dollars over a 35-year period.

The CONAES Risk/Impact Panel concluded that hydroelectric power is the most destructive to ecosystems. Biomass is nearly as destructive: use of land, depletion of fertility, use of fertilizers, risk of fast-growing plants developed. Among fossil fuels, shale oil and coal-derived liquids are probably the most damaging. Nuclear is relatively small, but light-water reactors require more mining of uranium (which fast-breeders would avoid). Solar ecological impact is probably mild, but poorly known. Ocean Thermal Electric Conversion (OTEC) might cause important ecological impact.

All these matters are discussed further in Chapter 10 and in Volume 2.

Ford Foundation — In 1979 Hans Landsberg of Resources for the Future (RFF), chaired a short-term study[2.8] under Ford sponsorship. The study wisely pointed out that keeping abreast of day-to-day developments is the job of the press but that, even in the twenty-year period they considered, serious shocks and surprises are certain to occur; surprises will be both pleasant and unpleasant. "The future of energy costs and world prices over our twenty-year period is essentially unpredictable . . ."

The U.S. should use some ingenuity, rather than brute dollars and obvious massive programs, to solve many of its energy difficulties. Since our energy needs are almost certain to project us further into environmental and social costs, we must regard them as part of the problems to be solved, rather than separate impediments.

If the U.S. elects to produce, say one million barrels per day of synthetics, 1/8 of the then current U.S. oil imports, at least $40 billion of capital and a ten-year lead time would be required. RFF noted that the total costs of producing oil in the Middle East was less than a dollar a barrel. MidEast production could be improved by convincing them that there are more attractive investments than oil in the ground.

"Because the energy problem is primarily one of cost, a successful energy R&D program is one that lowers cost (including external costs due to environmental damage and import dependence); a project that simply adds to the long list of known ways to get expensive energy is of little value. . . . Barring misguided public policies, nations will presumably proceed from conventional to unconventional resources by minimizing their rate of cost increase."

There are no energy options without drawbacks. "Even various solar possibilities entail adverse social, economic and environmental effects of different types and magnitudes, on different time scales, and affecting different regions in different ways. Even the 'best' choice for a nation will have drawbacks for some people, in some places." Solar energy is downplayed because, ". . . for a long time, much longer than our twenty-year perspective, physical scarcity in nonsolar energy is not the problem."

Harvard — The 1979 Committee for Economic Development[2.9] states, "There is a fundamental reason why the question of how much petroleum, gas and coal exists does not admit a definite answer. It is that the amounts of fuel that can be economically exploited depend on the prices people will pay for them. Even from abandoned deposits there is oil to be had at higher extraction costs. . . . The 'energy problem' is not best described as a comparison of demand with supply and the emergence of a gap between them, but as a prospective rise in the cost of fuel."

"Just knowing whether or not some important synthetic fuels would eventually be competitive, or knowing the world fuel prices at which they become competitive, could help to avoid serious mistakes in energy planning. Synthetic liquid fuels at a premium above the world price of oil, could be worth their cost if they reduce oil imports, even though the consumer would not pay that price."

Harvard Business School — The Report of the Energy Project[2.10] looks at the energy situation from a more quantitative viewpoint and discusses various models available. It includes a history of the oil situation and chapters on natural gas, coal, nuclear, solar and conservation. It explored how differences in assumptions could vary forecasts for 2000 from +60% to +230%. Due to its large market and resources, the U.S. tends to pull other nations into similar energy policies. The purpose of U.S. energy policy should be managing the transition from a world of cheap imported oil to a more balanced system. The U.S. will be fortunate if it finds enough new oil and [illegible] to maintain production levels. Increased price may be more important, by reducing consumption, than increased production.

Environmental and social considerations of energy sources, especially coal and nuclear are discussed at length, as well as problems with imported oil. The free market will probably not correct nor eliminate its price distortions.

The Global 2000 Report to the President — This federal report[2.11] released in January, 1981, is concerned with all aspects of the economy. With respect to food, it observes, "Most of the elements contributing to higher yields — fertilizer, pesticides, power for irrigation, and fuel for machinery — depend heavily on oil and gas." The LDCs will have trouble meeting their energy needs and the outlook is black for the quarter of mankind using wood for fuel. There will be continuing depletion of the world's forests.

"By 2000 nearly 1,000 billion barrels of the world's total original petroleum resource of approximately 2,000 billion barrels will have been consumed. Over just the 1975-2000 period, the world's remaining petroleum resources per capita can be expected to decline by at least fifty percent. . . . Most nations are likely to be still more dependent on foreign sources of energy in 2000 than they are today."

Brookings — In a 1979 report, ***Setting National Priorities — 1980s***[2.12] edited by Pechman, the energy situation is considered as a part of the entire international situation. "International cooperation is impeded by lack of understanding of how the international economy works, by clash of national

interest and by universal unwillingness to surrender national sovereignty. The problem is compounded for the oil-importing countries."

"Energy policy, especially that for oil, will be crucial. Inasmuch as a consumer-producer agreement on oil supply and pricing seems unlikely, the Atlantic countries will have to concentrate on conservation and the development of alternative energy sources. A more effective international policy for conservation can be achieved. Nuclear safety, the international regime for nuclear fuel services, and environmental problems associated with increased coal use will require the cooperation of the Atlantic countries."

North-South: A Program for Survival — Reports on a 1980 study conducted under international sponsorship, chaired by ex-Chancellor Willi Brandt of the Federal Republic of Germany (FRG), and popularly called "The Brandt Report." [2-13] Unfortunately, as noted by ***The Washington Post***, the report was issued when other news was occupying the world stage and, as a consequence, received little attention. It is concerned with the entire world situation; it contains one chapter specifically on energy affairs.

It points out the crucial role of petroleum and liquid fuels in world functions and survival. "All parties have a mutual interest in creating an international framework and political climate for trusting collaboration, for long-term exploration and development of energy and an orderly transition from oil to renewable sources of energy." Steps toward an an international policy are needed immediately and prices will play an important part in the transition. "Special arrangements including financial assistance are needed for poorer, developing countries."

The report notes that the first urgent need is toward reforms and stability in international currencies. "We believe, however, that the world cannot wait for the longer-term measures before embarking on an immediate action programme for the next five years to avert the most serious dangers — ." Elements of this action should include:

1. A large-scale transfer of resources to developing countries.
2. An international energy strategy.
3. A global food programme.
4. A start on some major reforms in the international economic system.

For a reader interested primarily in aviation or even U.S. fuel prospects, it is not believed justified to dwell longer on world energy prospects or on the significance of the numbers. They will be encountered later in this volume from the perspective of the U.S., as well as later in Volume 2.

For more quantitative data on world energy, the author believes the most useful, convenient reference of the world energy picture is compiled by Dr. Joseph D. Parent of the Institute of Gas Technology.[2-14] Fortunately, his current issue is also probably the latest global compilation available; its analysis begins with the 1980 WEC data.

Global Carbon Dioxide — There is world-wide concern about carbon dioxide because of the "greenhouse" effect it exerts by trapping heat within the earth's atmosphere. Like the glass in a greenhouse, carbon dioxide is transparent to solar radiation. But when solar radiation is absorbed by the earth's surface and re-radiated as infra-red heat, the carbon dioxide is opaque and traps the infra red. The question is whether this heating effect is enough to change world climate and, if so, what will be the effects in various parts of the world.

This problem is complicated, not only through the use of carbon dioxide by chlorophyl in manufacturing plant food, as well as by deforestation and burning of forests, often from natural causes, but by interaction between atmosphere and oceans, where tremendous amounts of carbon dioxide are held in solution. Further, volcanic eruptions release carbon dioxide (and also dust, which can reflect sunlight before it reaches the earth and reverse the heating process), while enhanced oil recovery is looking eagerly at natural carbon dioxide wells as a source for flushing greater quantities of oil from depleting fields. Will EOR processes of this type inject more CO_2 than they release? Will the amount be of any consequence?

This subject is reviewed in more detail in Chapter 10 and Volume 2, but the situation can be summarized very briefly: Burning of any hydrocarbon fuel releases CO_2 into the atmosphere. So do many industrial processes. Most synthetic fuel production will release more CO_2 in their manufacturing process than when the fuels are finally burned, which also releases the conventional amount of CO_2. Considering the likelihood that these activities will increase, while deforestation of world areas (which has a bad history and may be worsened by operations in areas like the Amazon) may increase at the same time, some concern is justified.

Unfortunately, as in attempting to answer other climatic questions, the lifespan of man's measurements has been short in comparison with world temperature cycles, deduced from geological and other evidence. In a ***National Geographic*** article of November 1976[2-15] it is concluded that, "We are living in one of the warmest periods of the past million years." The data show that our past 10,000 years have been unusually warm and that there have been only three such periods in the last million years. That is, fewer than 50,000 years of the past million have been warm enough for modern agriculture. *If we are living in a rare warm period which represents less than half a percent of the earth's normal climatic history, we might conjecture that we* should encourage, rather than discourage, future atmospheric heating.

The trouble is, we don't know when the next cold cycle might begin. We could heat the globe too much before the colder weather arrives . . . or we might detain the cold cycle from its "normal" occurrence. To further confuse the picture, the Library of Congress advises that data recorded at both the earth's ice caps can be interpreted to indicate that the trend toward the next ice age started in 1960.

At the specific request of Congress, the National Oceanic and Atmospheric Administration is about half-way through a two-year study to make the best assessment possible of CO_2 in the atmosphere and its probable effects, exploiting present data and techniques. The Meteorological Office of the UK has undertaken a parallel study. So, in one to two years, results should be available as far as analytical technology can forecast. But it is generally estimated that at least ten to twenty years of recorded weather may be required to test the theoretical results.

The answer by that time may be rather academic. The consensus seems to be that by the time we have enough data to confidently read the result, if CO_2 does undesirably warm the atmosphere, the process is likely to have become irreversible. If this likelihood should become firmly established or if popular opinion should become as militant as in nuclear energy, there might be strong inhibitions against burning hydrocarbon fuels and, in particular, manufacturing synthetic fuels from hydrocarbon bases.

This contingency is one of the factors which encourages hydrogen advocates. In the near term, CO_2 repression could also mean repression of hydrogen manufacture, because production of hydrogen from hydrocarbon feedstocks, like other synthetic processes, generally releases large quantities of CO_2. But hydrogen produced by water-splitting, electrically, chemically, photochemically, or by combinations of these processes, using, for example solar, nuclear or geothermal energy as the driving force, would release no CO_2. And, of course, hydrogen as a fuel releases only pure water vapor (unless in the process air is exposed to high temperatures, which can combine natural oxygen and nitrogen into varieties of NO_x).

But what if more CO_2 should be consumed in new fuel production or other industrial processes; what if CO_2 is used more extensively in greenhouses and other horticulture to accelerate plant growth? If ocean culture becomes practical, can it be stimulated by CO_2 injection? Today there are already processes for which CO_2 is manufactured at a cost. Perhaps man can develop the ability to create or stabilize an optimum CO_2 balance in the atmosphere, if he can determine and agree on what that should be.

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Chapter 3

U.S. Aviation in the Fuel Market

Board Room Briefing No. 3

Refer again to the BRB items of Chapter 1; they are as important to aviation fuel prices and market forces as those added here:

1. U.S. aviation fuel demand increased rapidly, nearly 10% per year, from 1976 to 1979; it is unlikely to increase at that rate again within the foreseeable future.

2. The 1976-79 increase in jet fuel consumption did not even register on the scale of national petroleum consumption, which experienced a net decrease during the same period.

3. Due to the controllers strike and decline in the economy, aviation fuel consumption has declined in 1980-81 and will probably continue down slightly through 1983. Toward the end of 1983 it should begin a recovery and, after 1984, resume a "normal" growth of about 5% per year or less.

4. An industry consensus today would say that U.S. oil production peaked in 1970 and that world oil production must decline from 1990 onward. Many forecasters and observers now consider that view too pessimistic. The outlook appears to be improving rapidly with time. It is likely that a new consensus in 1982 will see U.S. oil production exceeding that of 1970, possibly for another ten to twenty years, and world oil production ***capacity*** sustained for twenty to thirty years.

5. While only about 15% of U.S. refineries produce jet fuel, they are the larger ones, representing about 45% of national refining capacity. Although their jet fuel production consequently occupies a small part of their capacity, it claims a premium price and so refiners give it more consideration than the straight quantity would suggest. It can be important to the refinery's profit margin. Refineries with low jet production should be able to produce greater quantities of aviation fuel without major alterations, but at a decrease in competing products.

6. Fuel conservation is already highly developed in aviation and is making good progress in other areas. But, while aviation cannot readily substitute other fuels, stationary powerplants and other types of transportation are likely to move increasingly out of oil products. Even if fuel prices soften, built-in momentum in conservation and substitution should suppress demand for 5-6 years. The net effect should be more fuel available to aviation, although diesel competition with jet fuel will increase.

7. The airline industry is perceived by lenders to be a below-average investment opportunity. In the past, aircraft have represented good security on the investment and older aircraft were retired only as they lost passenger appeal or increased excessively in maintenance costs. Fuel consumption is now such a large factor in airline profitability that older, less fuel-efficient aircraft lose their value more rapidly. The pressure on airlines is increasing. Those that suffer from fuel inefficiency may be unable to finance the new aircraft that would make them competitive.

8. Before the oil price rise of 1973-74, the world market price for crude oil was lower than replacement costs (exploration and development) for new crude. With world demand increasing rapidly at that time toward the world production rate, a sharp runup in price was inevitable. The OPEC embargo and price increases simply accentuated and took advantage of the market situation which had developed.

9. The most influential factor in short-term prices (other than a crude-oil delivery disruption) is OPEC production policy. OPEC is scarcely an ideal cartel, with its many internal stresses. But Saudi Arabia produces almost half of OPEC's supply and is able to vary its production rate significantly without harming its economic interests. So near-term price is effectively dependent on Saudi Arabia's production policy.

10. With world demand now about 2 million b/d (4.5%) below capacity, and production controlled voluntarily by producers, price should now be the key variable in supply/demand forecasts. On the basis of economic supply/demand, a 4% real price rise per year would decrease demand too much below capacity to suit producers. With no real increase in price (0%), the demand would soon exceed production capacity. It therefore would appear that a long-term real annual price increase of about 1-2% may be expected. That may be another prediction fated for early revision!

11. As of today, complete arrest of oil production from any single oil-exporting country, other than Saudi Arabia, can be made up by excess Saudi capacity. Oil production should increase in countries outside OPEC. This may introduce another degree of freedom to the market.

12. The most influential factor in U.S. energy has been the change in domestic oil policy. Before 1970, oil was rapidly penetrating a larger share of the fuels market. Now oil is being backed out of the U.S. market, about 5% per year. The wellhead price of natural gas is about $10 per barrel of oil equivalent, but natural gas is still demand-limited because of restrictions against its use. A change in gas policies could have a powerful effect on U.S. fuel.

13. Without considering "revolutionary" concepts such as greatly expanded use of natural gas or methanol, U.S. oil demand will drop from about 17 million b/d in 1980 to about 14-15 million b/d in 1990.

14. The effects of adverse national political regulations and policies can be seen readily by considering Canada. While Canada has plentiful oil and is generously supplied with natural

gas, its pricing policies and domestic-ownership policies have stifled production, throttled investment from the U.S., and stunted its foreign exchange rate. Western provinces are prohibited from producing as they would wish, while eastern provinces are buying crude oil abroad. At the same time, the eastern provinces have excess capacity for producing electricity.

Aviation Short-Term Fuel Demand

The present aviation short-term fuel demand forecast is under revision within FAA because of changes in outlook for the short-term GNP as well as effects of the controllers strike on traffic levels. This situation is unprecedented because FAA aviation forecasts are normally released in September of each year. It is the September 1981 issue, therefore, which was still in revision in early 1982, and it may remain in that state for some time. Unless the GNP forecast is revised significantly, however, the general picture can be deduced about as shown in Figure 3-1.

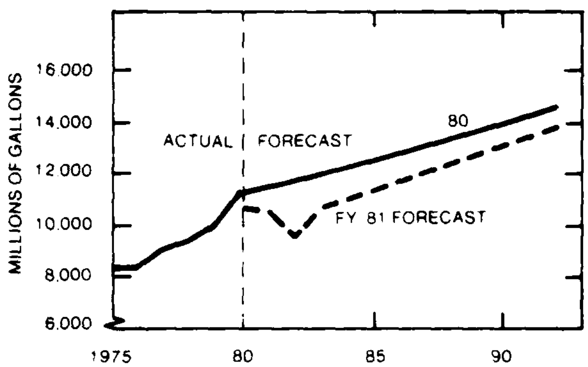


Figure 3-1
U.S. Aviation Fuel Demand

Figure 3-1 shows that aviation fuel demand increased almost 10% per year between 1976 and 1979. The FAA 1980 forecast,[3.1] anticipated a further increase to the end of that year, but fuel demand was reduced due to the controllers strike and artificially curtailed air traffic. Fuel demand has definitely fallen since that time and is expected to drop further until September, 1983. While new controllers are being trained, air traffic control (ATC) system capacity will drop somewhat further due to: 1. reducing overtime and increasing vacation flexibility; 2. returning military controllers to their stations; 3. normal retirements and return of specially-assigned FAA personnel to their previous roles within FAA. As the new controllers come on line, there will be some one-for-one reduction in capability where they replace more experienced supervisory and lower management FAA personnel.

Although extensive training is progressing in the facilities, "... air traffic will continue to be regulated to a decreasing degree throughout the next three years to avoid extreme traffic peaks."[3.2] This next three years is therefore regarded as a period of second impact on fuel demand. By relocating controllers from towers at low-density fields, the traffic-handling capacity at airports has suffered less than at the 20 continental air route traffic control centers (ARTCCs), which guide traffic between airports. None of these centers can be closed, even on a short-term basis. So the centers are and will continue to be the factor limiting ATC throughout the recovery period.

After September 1982, traffic capacity should recover fairly rapidly through the following twelve months so that, in September 1983, ATC capability should have returned to full strength. As Fig. 3-1 shows, it has been subjectively assumed that there will be some inelasticity in total recovery, also partially in anticipation of a forthcoming lower growth rate for the GNP.

But, in general as shown after 1983, the rate of growth in aviation fuel demand is expected to resume a level comparable to that forecast in September 1980. This amounts to a fuel growth of about 2% per year. Among other factors which will determine if this rate is realized, is the effect of further fuel conservation and the introduction of new, more fuel-efficient aircraft into the airline fleet. For further discussion and consideration of those effects, see Chapter 11 in this volume.

The subject of aviation fuel demand elasticity versus fuel price may be conspicuous by absence of its analysis in this report. The Economic Analysis office of the American Petroleum Institute completed a preliminary regression analysis in January 1982, looking at GNP, disposable income, fuel price and related factors. While a relationship was developed and can be used to describe past events, API was not satisfied with the results. Its forecasting value is dependent on assuming that airline operations and fare structures can respond to price increases in the future as in the past, which they definitely cannot. (Most fuel-conservation measures already accomplished are non-repeatable.)

Regardless of mathematical sophistication, the result probably includes too many unassessable factors, such as airline competition, to yield a generally applicable result. FAA analysis has shown that about one-third of a fuel price rise is passed on in ticket price. The other two-thirds is apparently absorbed in the airline. As far as ticket price is concerned, traffic elasticity is considerably more definitive: a 10% increase in fare price has been found to produce a 6.4% decrease in passenger traffic.

This report is not primarily concerned with such fine-grained supply/demand affairs. Further and fortunately, the outlook is strongly for stable aviation fuel prices over the next several years, in the absence of major disruptions in foreign crude supply. To complete this intentional evasion, any significant fuel disruption scenario will possess major peculiarities which may drive both the fuel price and demand situations more directly than will interaction between the two factors.

So the conclusion here is that aviation fuel demand will climb at about 5% (or less) per year over the next ten years, as compared to 10% per year growth during the past several years. This conclusion therefore de-emphasizes two factors that frequently have been highlighted concerning an expected significant growth in aviation fuel demand. First, the growth rate should be relatively small; second, the rate of growth is almost certain to be half or less than it has been recently. So, instead of gearing up for a major surge in aviation fuel demand, as many have predicted, the outlook suggests a very moderate change at the most.

Aviation Fuel in National Petroleum

From a national or a refiner's viewpoint, the history of aviation fuel demand is seen better in Figure 3-2. It is well for the aviation user to consider his industry in this perspective. Here it is apparent what a small proportion of the national petroleum scene the aviation market occupies, about 5% in the past.

The aviation percentage of the market increased to 6% in 1980 and, even with less aviation fuel used in 1981, may actually show a further percentage increase for the 1981 year. But, with aviation fuel demand having dropped in 1980 and 1981, it is very evident that the climbing share of aviation fuel in the market is due, not at all to the increase in aviation fuel used, but from the decrease of total petroleum products supplied in the U.S. As of the end of 1981, it appeared that total U.S. petroleum used again will have dropped at least as much in

1981 as it did in 1980. Since aviation fuel also dropped in the same period, it is simply a question of which decreased the larger percentage.

So reports in aviation news media and expressions from refiners foreseeing a significant new upward share of aviation fuel in the market must be considered in context. The trend is true and, except for less demand in 1980, '81 and '82, the aviation share trend should be upward. But, except perhaps for some individual refiners, the popularly forecast "growth" in aviation fuel demand does not appear significant for some time to come. By that time, the trends for diesel and other middle-distillate fuels are likely to have more influence on the total picture and on the middle-distillate situation than is aviation jet fuel.

Aviation Fuel Prices

Aviation fuel prices have impacted the industry much more than has fuel demand or fuel availability. In fact, except for the initial OPEC embargo of 1973-74, availability really has not been a serious problem. But fuel price has had a most serious effect on airline profitability. Fuel price is shaping the new direction in aviation and is expected to play a firm position throughout the future, as far as can be seen.

The driver of this situation is foreign crude oil prices, as was seen in Figure 1-1. Due largely to refining, distribution and other costs, *jet fuel prices should not necessarily increase* as rapidly as crude prices. But, comparing the rates of rise in Figure 1-1 with Figure 3-3, the effect is erratic and dramatic. During the 1973-74 crude price surge, crude increased by a factor of 6, a rise of 500%. At the same time, U.S. domestic jet fuel price about doubled, for a 100% rise. When in 1979-80 crude oil prices rose another factor of 2.5, for a 150% rise, jet fuel then outstripped the crude rise. Jet price rose by a factor of four, for an increase of about 300%. So in one case, jet fuel rose only one-fifth the rise of crude prices; in the latter case, jet fuel prices rose twice as much. Why?

Among other things, at the time of the first crude price rise, 1973-74, some airlines held long-term contracts for jet fuel delivery, so the rise in crude price could not affect them immediately. Many suppliers were getting their crude from domestic sources, where the price was still rigidly controlled. Then, of course, there were secondary effects such as the slate of products and prices for individual refineries, which swung according to the crude supplies they encountered and the customers they were able to supply. The complex situation does not lend itself to conclusive analysis or to forecasting events during future disruptions. Too much depends on the characteristics of the next crude-oil disruption, its abruptness, and market conditions at the time it occurs.

The effect of fuel prices on the aviation economy is well represented by Figure 3-4, from Boeing, based on CAB data. Figure 3-4 shows the major components of U.S. domestic airline direct operating costs (DOC) from 1968 to 1979: fuel, crew, maintenance and aggregated other costs. It is only too clear how fuel has surged ahead of all other DOC items from 1973 onward. As a result, Figure 3-5 shows that fuel, which had traditionally accounted for 25% of DOC, now has escalated to nearly 60%. The exact amount, of course, varies from airline to airline, by aircraft type, from route to route, and even from flight to flight. But the outcome is inexorable. Fuel has been established as the major component in airline costs and, therefore, in airline profit-and-loss balance.

As will be seen in Chapter 11, the profit margin is presently very thin for U.S. airlines. A small increase or decrease in fuel economy can spell the difference between profit and loss. By the same token, any increase in fuel prices must be handled most

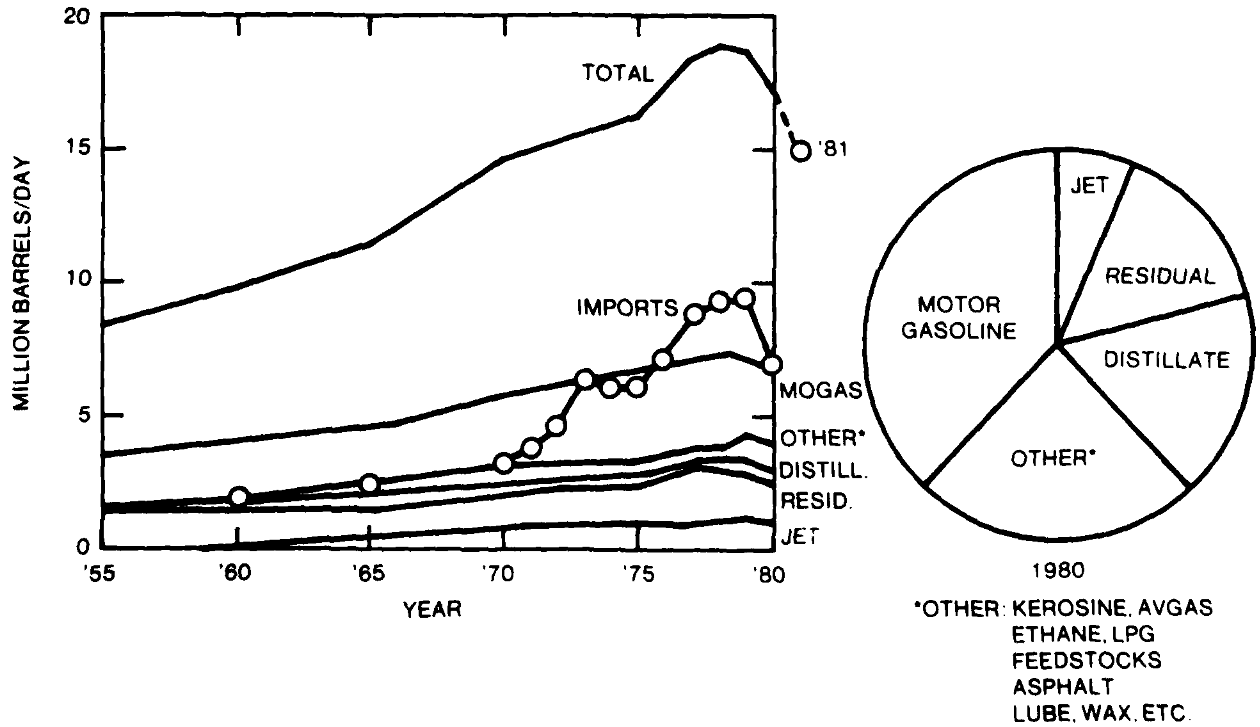


Figure 3-2
U.S. Petroleum Products Supplied

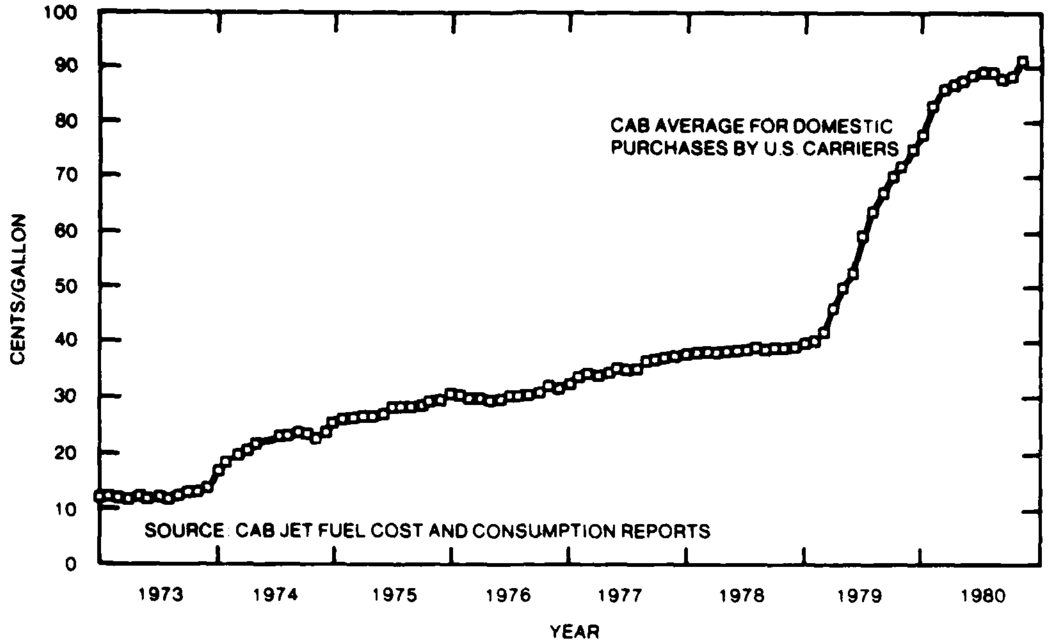
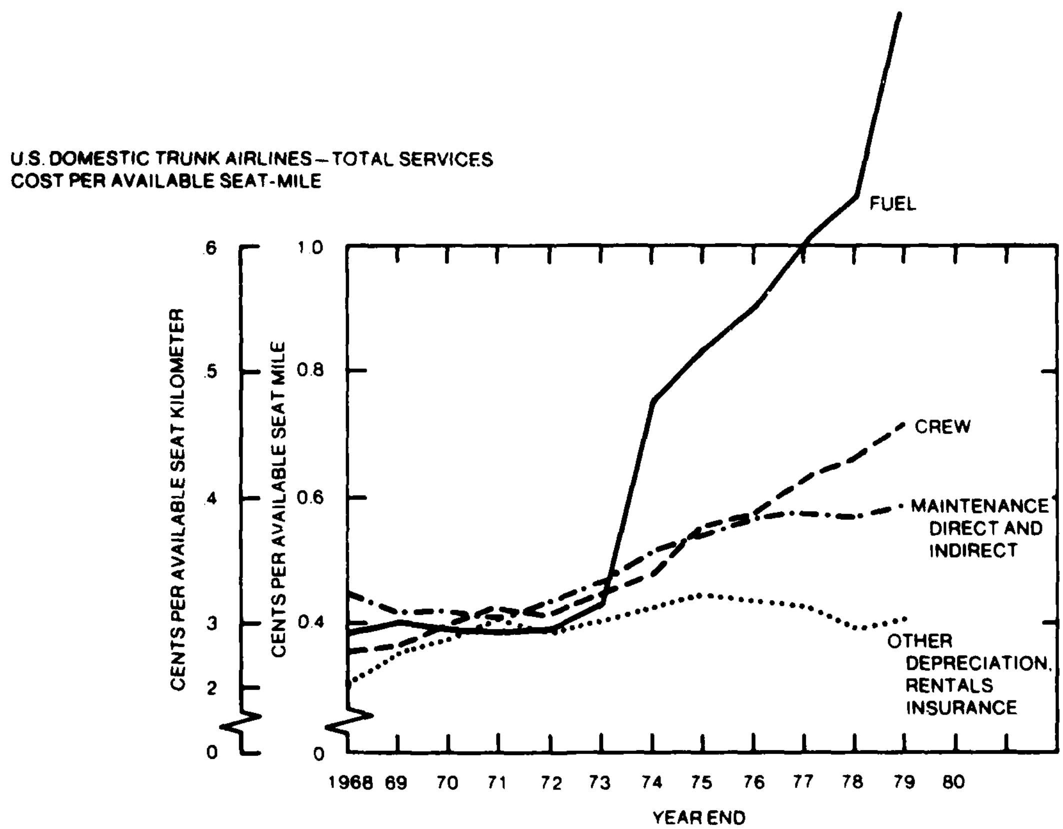


Figure 3-3

U.S. Domestic Jet Fuel Prices



SOURCE: CAB FORM 41, SCHEDULE P5

Figure 3-4

Influence of Fuel Price

Direct Operating Cost Elements (Current Dollars)

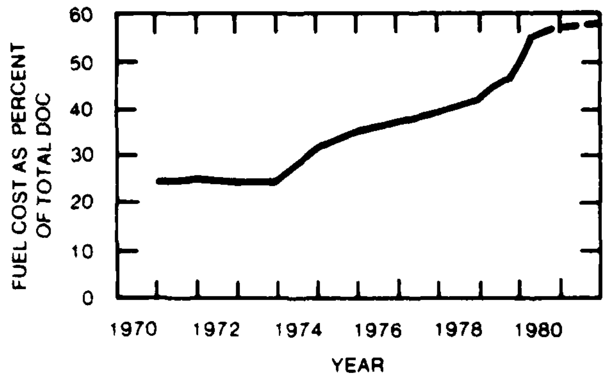


Figure 3-5
Fuel Price Impact on DOC's U.S. Trunks-Domestic Service

judiciously by each airline in order to maintain a profit at the same time as preserving its market share.

As has been said earlier, the present expectation is that crude oil prices and jet fuel prices will hold essentially stable for at least the next few years, possibly as long as five to ten years. This conclusion does not include the likelihood of a major foreign crude delivery disruption, and consequent possible fuel price runup, at virtually any moment. So, except for the probability of disruption, the jet fuel price situation looks better than in recent forecasts.

For example, Figure 3-6 shows FAA's reaction to events over the past three years. By plotting Oil and Gas Deflator (aviation studies usually identify the price of fuel by this term, harking back to the propeller days when gasoline and lubricating oil costs were lumped together), the figure shows fuel costs relative to the rest of the economy. The label "deflator" has caused trouble to some readers, particularly when applied during a period of general inflation. What this means is that the GNP is "deflated" with respect to the price of fuel. At any rate, it is the conventional term for showing fuel price effects in aviation economic analyses. An increasing deflator is an increasing rise in fuel price, expressed in percent and referenced to some convenient year.

Following the '73-74 price rise, FAA (and many others) assumed that OPEC would stabilize future prices at a moderate rate above the economy, as designated by the line from the FAA FY '79 forecast in Figure 3-6. By FY '80, the two Iranian disruptions added their impulses to OPEC's assessment that oil was not priced snugly against the world marginal replacement cost. Based on these price actions, FAA was whipsawed into its '80 forecast. Considering decreasing world demand and "stabilized" OPEC prices, the FAA forecast which was to have been released in September 1981, then was adjusted well below the FY '80 curve. Now, with world demand below world petroleum production capacity and with production cut back accordingly, it may be expected that the FAA '81 forecast when released will be revised downward from the one shown here in Figure 3-6.

U.S. Short-to-Medium Term Oil Outlook

The outlook for U.S. petroleum supply is improving rapidly, at least from the viewpoint of this spectator's assessment. There is another substantially more conservative view, and the two are discussed further in Chapter 4. As has been mentioned before and, at the danger of repetition will be mentioned again later, an increase the potential supply of domestic U.S. oil (or other non-OPEC oil) will not necessarily reduce crude oil prices if exploration and development costs are high.

But the converse would have serious consequences much earlier. If, as many believe, the U.S. will never again approach its domestic oil production level achieved in 1970 and if the world production capacity tops out in the 1990s due to inevitably lower finds than the production rate, crude prices must continue to rise rapidly and with little or no significant interruption. These dire effects may be delayed by conservation efforts and may be offset to some degree by alternative energy sources. But, if this thesis is correct, oil would inevitably become scarce and expensive much faster than conservation could mitigate, or than alternatives can be brought on stream.

The author's more optimistic view is built on a variety of evidence, but assembled largely from two sources: 1, the 1980 annual reports from major oil companies released in early 1981; 2, the "API (American Petroleum Institute) issue" of the *Oil and Gas Journal* November 9, 1981, in which the U.S. petroleum outlook is summarized. This summary is gathered through nine articles from the major oil companies (many of them authored by the same CEO who signed the company's annual report), as well as additional assessments by the editor of *O&GJ* and the president of a prominent oil consulting firm. Admittedly, these views all come directly from the oil industry and, particularly in the case of annual reports, may be expected to be optimistic. But, on the other hand, members of the oil industry may be reluctant to forecast tremendous increases in supplies or the possibility of falling prices. Some of these same individuals and organizations have tremendous stakes in alternative energy projects which would be severely impacted by excessive optimism in the petroleum outlook.

Oil Company 1980 Annual Reports

The following excerpts from 1980 annual reports are presented in considerable detail for the convenience of those who wish a solid background or a closer feel for events as they developed during 1980. Those who are concerned largely with the present, may wish to turn to the ***Oil Industry Outlook***, the next section following in this report.

Company reports included are from: Atlantic Richfield (Arco), Conoco, Exxon, Gulf, Marathon, Mobil, Occidental, Phillips, Shell, Standard Oil of California (Chevron), Standard Oil of Indiana (Amoco), Standard Oil of Ohio (Sohio), Sun, Texaco, and Union.

Following their Highlights, **Arco** begins its report with "Essay: A New Outlook on Energy." It notes that, ". . . the penalties of dependence on foreign sources outweigh the rewards of artificially cheap fuel and the profligate consumption which it inspired." Then it advises that Arco is searching farther offshore, into the Appalachian Province, the Western Overthrust Belt, deeper into Texas, Oklahoma and Louisiana, and searching the Alaskan frontier. "And competition is keen in the search for alternatives such as coal and solar, and for a whole range of other technologies to produce more energy."

"It is too early to state with certainty what impact this work will have on U.S. petroleum production, but the first signs are promising. Natural gas prospects are even more encouraging than oil. Last year, the industry apparently came close to replacing the gas consumed in the country, a striking turnabout from the declining discovery rate of a few years ago." Next it speaks of rising costs and the sizes of investment required, the drop in U.S. oil demand, and the "startling" conclusion of Arco economists that crude ". . . imports in 1990 may be about level with today." The essay mentions risks of Middle East instability, and the fact that, ". . . U.S. petroleum earnings over the next few years will provide only half the cash that industry will need to find and develop new domestic energy

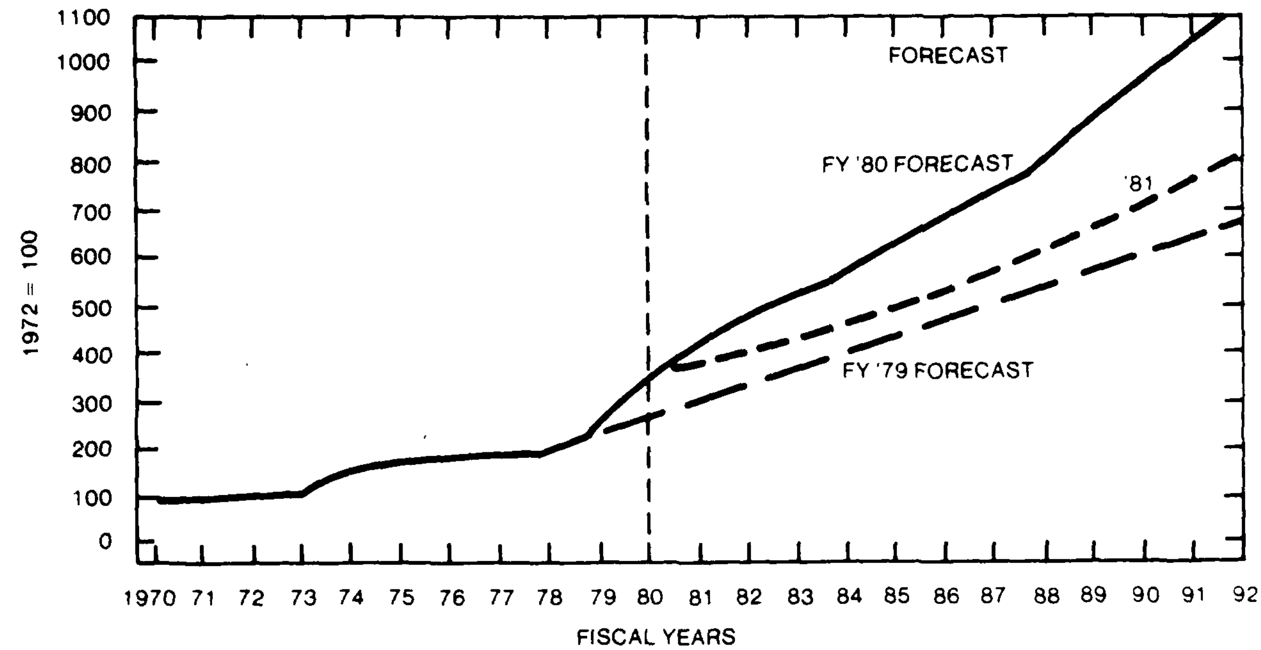


Figure 3-6
Oil and Gas Deflator

Taxation policies that siphon off or divert funds from these efforts can have dire consequences for the nation." It expresses strong belief in environmental protection, tempered with balanced federal land policies. (Arco closed the Anaconda smelter in Montana during 1980 after assessing its environmental/economic options).

"Despite these areas of concern, . . ." the outlook is brighter and Arco is initiating a $25 billion investment program over the next five years, of which $16 billion will go into domestic oil and gas. Ten percent will pursue foreign oil and gas opportunities. Investment in refining, marketing, transportation and chemicals will be "relatively modest" but, while concentrating on oil and gas, Arco will continue to invest in coal development and R&D. Details of the report outline the company's increased activity in petroleum exploration, development and production. During 1980, Atlantic Richfield sold its interest in the Colony Development oil shale operation and earned comments from industry wags that Arco is the only organization which has shown a profit in shale for over a hundred years. Arco retains some shale holdings through the Arco Coal Company.

Alphabetically first, Arco provided a convenient framework for assessing the remaining reports. Highlights are included where they emphasize or depart from Arco's report and planned program.

Conoco is encouraged by the nation's approach toward a balanced energy policy, with less dependence on foreign oil, increased domestic production and conservation, and increased natural gas prices. A 30% increase in exploratory domestic drilling between 1978 and 1980 is yielding positive results in reserves. Coal has also contributed to reduced dependence on foreign oil. "However, coal's full potential will be realized only if government regulations are amended to remove the measures that increase the cost of production and limit consumption without providing tangible improvement of the national environment, public health, or worker safety." In 1980, the windfall profits tax and the Alaska National Interest Lands Conservation Act (only about 9% of all federal lands are under lease) are expected to hamper the industry's effort in domestic energy development. Conoco reports, "A total of 400 employees are assigned full-time environmental responsibilities, including *pollution control and land reclamation*."

The removal of controls on domestic crude oil is expected to contribute positively to the nation's energy plan. This process could be enhanced by decontrol of new gas and review of windfall profit tax rates. Conoco notes that the windfall profits tax is designed to capture three-fourths of the revenues generated by crude oil price decontrol.

The nation's coal mines have excess production capacity of more than 100 million tons per year, equivalent to more than a million b/d of oil. On coal, ". . . Congress should balance the desire for clean air with our nation's critical need to improve energy security, revitalize industry, and expand employment opportunities."

Conoco's 1980 additions to domestic petroleum reserves exceeded domestic petroleum production on a Btu-equivalent basis, the first year since 1968. Secondary recovery, mostly waterflooding, accounted for 46% of domestic production and largely accounted for the increased reserves. Conoco's natural gas production decreased 6.7%, principally due to reduced customer purchases. U.S. production of natural gas has held steady at approximately 20 trillion cubic feet during 1980, about the same over the past six years.

Exxon says, "The United States is at last adjusting to the realities of a changed energy environment. . . . Higher prices for heating oil and gasoline have created problems for many people, including some of our shareholders, and they have not hesitated in expressing their feelings to us. Explaining that the country would have been better off without price controls in the first place offers little consolation.

"By the end of the century, we expect total energy demand in the United States to be somewhat higher than it is today, but the share of energy supplied by oil and natural gas will decline from

around 75% now to about one-half. That assumes that stepped up drilling efforts will result in new discoveries, particularly in frontier areas, to offset declining production from mature fields. Some of the difference will be made up by increase of directly burned coal and nuclear fission, although environmental concerns and regulatory problems will probably retard the grow.h in their use. Even so, the country will still need more liquid and gaseous fuels than it can produce through conventional means." The gap represents an opportunity for synthetic fuels.

"We see no lack of investment opportunities. Exxon's capital and exploration expenditures are expected to grow." 1981 capital and exploration expenditures will be $11 billion and they ". . . expect that such expenditures will grow over the next four or five years in real terms and over the rate of inflation."

"For the first time since 1971, Exxon's proved oil and gas reserves increased (over that produced)." Domestic oil production was essentially level with 1979. Natural gas sales volumes were down 7%. "Supplies from Saudi Arabia, the company's most important source of crude oil, were down slightly from 1979." Exxon is pursuing EOR with a surfactant chemical and with the largest nitrogen gas injection project in the industry. Potential production of 140,000 b/d from heavy oil at Cold Lake in Canada was delayed by disagreements between Alberta and Ottawa.

"For the first time, Exxon's coal business in the United States was profitable enough to cover new business and mine development costs worldwide. Production from Exxon USA's two underground mines in Illinois and two surface mines in Wyoming increased 33%." Exxon is participating in a coal mine development in Columbia and in building a European coal import terminal. Operating losses have continued in uranium, despite renegotiated contracts in about three-fourths of Exxon's contracts. Exxon bought Arco's 60% interest in the Colony shale oil project, which is scheduled to produce 47,000 b/d, starting in 1985, with total cost estimated over $2 billion. Exxon is exploring a joint shale project in Australia, is testing the Exxon Donor Solvent coal liquid process, and plans a $500 million, eight-year program for coal gasification in Rotterdam. As have several of the other oil companies, Exxon has affiliate interest in solar photovoltaic development.

Gulf reported record income and increased dividends, but was, ". . . *buffeted by the winds of change.*" They note three major events of 1980: 1, the tightening control of foreign supplies, 2, the improvement in U.S. regulatory climate and, 3, the worldwide sharp decline in energy consumption.

"As recent as 1974, more than half of Gulf's net income was earned outside of North America, and of that amount, a major portion was derived from oil production in two countries — Kuwait and Venezuela. Despite the nationalization of those properties in 1975, our earnings since then have doubled — and the source has shifted significantly. Last year, 79 percent of Gulf's net income came from North America . . ." Pursuing development in the U.S. and Canada, Gulf invested $3 billion in capital last year, a 19% increase from 1979, and plans $4 billion for 1981.

"Where oil is concerned, nationalistic measures are not limited to the OPEC producers. The Canadian government has proposed measures which would grant preferential tax incentives to Canadian-controlled companies, give the federal government the right to acquire without compensation a 25-percent interest in any frontier discovery, and require 50-percent Canadian ownership for any major new project on federal lands. . . . The British government has also proposed a fourth tier of taxes on already heavily taxed North Sea production, which could cause a delay in developing some new fields."

"The chief beneficiary of (U.S.) crude oil decontrol, however is the government. Because of higher state severance taxes and the so-called federal 'windfall profits' tax, between 80 and 90 percent of the additional revenues derived from higher oil prices is going into federal and state coffers." Gulf hopes for elimination of the 30% tax on new oil to stimulate exploration, and natural gas pricing to "close the widening" gap between oil and gas prices. Even with an economic recovery in 1981, Gulf expected petroleum demand to grow only fractionally over the next five years.

". . . we firmly believe that the best strategy for Gulf Oil in the years ahead is to continue to pursue an aggressive energy-exploration program. . . . Despite the Company's aggressive exploration and development program, production of both crude oil and natural gas continued to outpace reserve additions. . . . The major focus of research at Gulf Science and Technology Company — Gulf's principal research division — is to develop and improve technologies for finding and producing oil and natural gas. . . . Research expenditures reached $134 million in 1980, an increase of 23 percent over the $109 million spent in 1979. . . . developments should greatly improve the Company's drilling success ratio in the future."

Marathon reported first on its aggressive exploration program. "In the U.S. alone, our level of exploration activity more than doubled in the last three years. . . . "Our estimated total capital and exploration program in 1981 will surpass $1.2 billion, the largest in our 94-year history. . . . Nearly 70% of the 1981 capital program . . . is scheduled for development of oil and gas around the world." About 43% is in the U.S. "Our 1981 net production of liquid hydrocarbons in the U.S. will show a modest increase, assuming early approval by the Texas Railroad Commission to increase the allowable rate of production . . ."

"Marathon's principal reserves of oil and gas are located in the United States. To retain this strong position, we have greatly increased the level of our domestic exploratory work. Since 1977 Marathon has:

- Doubled our net acres of potential oil and gas lands in the United States, with particular emphasis on the Rocky Mountain States, the Gulf Coast states and frontier areas.
- Nearly doubled the size of our professional exploration staff.
- Increased our expenditures for acquisition of geophysical data by more than 400%.
- Nearly tripled our expenditures for drilling wildcat wells."

"Marathon drilled 106 exploratory wells in 1980, twice as many as in the previous year. Of these, 58 were successful in finding oil and gas."

"Essential for further progress is a national energy and economic policy which will responsibly encourage capital formation and stimulate the development of all our nation's energy resources. Steps leading to such a policy would include:

- Eliminating certain categories of crude oil from the 'windfall profit' tax to encourage increased domestic exploration and production.
- Providing for earlier termination of the 'windfall profit' tax on all categories of oil.
- Changing income tax laws to permit faster recovery of capital costs for business and to stimulate increased savings and investment by individuals.
- Developing a national refining policy based on competitive market forces, with emergency standby authority to allocate crude oil supplies to refiners who are the most efficient producers of the most needed products.

- Insuring that customer preferences determine how and by whom petroleum products are delivered to them in the marketplace.
- Eliminating the complex and unrealistic system of natural gas price controls that is now in effect.
- Opening additional federal lands for oil and gas exploration and adopting a more balanced approach toward environmental matters.
- Substantially decreasing the general regulatory burdens and simplifying reporting requirements imposed on the domestic oil industry."

Mobil is ". . . giving exploration and producing unprecedented amounts of new capital. . . . Mobil's success in exploration and producing demonstrates that the potential for discovering new oil and gas is not as limited as some thought. Our experience indicates that the finding of large new reserves is, in part at least, a function of willingness and ability to invest the necessary funds when opportunities arise."

"The government of Canada has made proposals to reduce foreign ownership and raise taxes, which, if not modified, could seriously hamper efforts of U.S. oil companies to find and develop oil and gas. Meanwhile, the province of Newfoundland and the Canadian government are both claiming interests in the offshore area where the Hibernia discovery was made."

"Funds spent for U.S. exploration rose approximately 50% over 1979, not including offshore lease bonuses. Results have been promising, particularly discoveries of natural gas in South Texas, West Texas, Mississippi, Oklahoma, and offshore Louisiana. . . . Tests were sucessfully completed in the Gulf of Mexico of a Mobil-developed technique for installing underwater flow lines at depths below those divers can successfully reach. This has the important potential for producing in waters deeper than 1,000 feet, where conventional platform development is not feasible."

"When completed in 1981, the 750-mile Petroline, being built under Mobil management, will provide a direct route to the Red Sea from Saudi Arabia's large oil fields in the east." (bypassing the Strait of Hormuz).

"Worldwide, Mobil carried forward a dual strategy in refining and marketing investment. The strategy focused on:

- Imroving Mobil's flexibility in processing a wide range of crude supplies including heavy, high-sulfur oils.
- Maximizing refinery yields of lighter, higher-value fuel products, such as gasoline, diesel, and jet fuel . . ."

In synfuels, "Mobil's emphasis will be to produce liquid fuels for use in transportation, for which no substitutes are readily available." In a joint effort with the government of New Zealand, Mobil began a complex to manufacture 13,000 b/d of high-octane gasoline from methanol derived by the Mobil-M process from New Zealand's large supply of natural gas. Mobil is a member of the Paraho group for producing shale oil in the U.S. Mobil is engaged with Tyco in silicon ribbon solar cells and, in 1980, started operating a seawater desalination plant with solar power in Saudi Arabia.

Occidental reported, "During 1980 domestic oil and gas exploration was at a higher level than in previous years, and we plan to increase domestic exploration further in 1981 and subsequent years." "Occidental's Logan Wash oil shale demonstration project . . . is progressing satisfactorily. Development of the Cathedral Bluffs joint venture with Tenneco is on schedule." "Exports of steam coal to Europe sharply increased in 1980 as utility and industrial plants there began switching from fuel oil to coal, and we expect this trend to continue." Oxy will open a new coal-handling facility at Baltimore in early 1982 and a new coal pier at Norfolk before the end of the year. A million-barrel-per-year coal-oil mixing plant was scheduled to demonstrate production during 1981.

"Occidental reached its present position in the oil industry through successful oil and gas exploration and we intend to continue to grow through increased exploration. We now have 17 active exploration offices around the world, 6 of which began operation in 1980."

At Cathedral Bluffs, Oxy and Tenneco were scheduled to bottom their three 2000 ft. shafts in 1981 and, in mid-1982, begin development of the underground shale mine for modified in-situ (MIS) shale oil production. (see Chapter 8).

"***Phillips Petroleum Company*** took major steps during 1980 to implement a strategy designed to cope with the coming decade of continued international tensions, uncertain oil supplies and rising costs. Key elements of our strategy include:

- A greatly expanded commitment to find and produce oil and natural gas in the United States.
- A continued effort to broaden overseas petroleum production, building on our strong position in the Norwegian North Sea.
- A growing involvement in developing alternate fuels, particularly coal and oil shale.
- An increased flexibility in refinery operations to handle a diversity of raw materials and to respond to shifting product demands.
- A selective expansion in chemicals and enlarged participation in the international chemicals market.

"In 1980 Phillips spent a record $1.67 billion — an average of $4.6 million a day — to find and develop energy resources, and expand and modernize refining, chemical and transportation operations. About 70 percent of these were U.S. expenditures. In 1981 spending for authorized projects is expected to increase with a capital budget of $3 billion, a 20 percent increase over the projects authorized in 1980. We increased domestic spending on seismic activity by nearly 60 percent and drilled or participated in 816 wells in 1980, a one-third increase over 1979."

"The energy outlook for the coming decade will be plagued by price and supply uncertainties stemming from international tensions. . . . A major step toward protecting the United States from future oil shocks was taken in January of this year with the federal government's decision to lift controls on domestic crude oil earlier than scheduled. . . . Even before the government's decision to remove controls early, the industry was responding strongly to partial decontrol. Nearly 63,000 wells were drilled in the United States during 1980, an all-time high. It is anticipated that record will be surpassed in 1981 with an estimated 69,000 wells expected to be drilled."

"Current air quality rules limit development and use of important U.S. resources, particularly coal. . . . Much of the energy and mineral potential of this country lies beneath land and waters controlled by the federal government. At the present time, use of many of these areas is limited to recreational purposes and scenic preservation."

"Although scarcely noticed by the public, increasing taxes on petroleum operations are having a direct impact on the consumer's pocketbook as well as a long-term effect on the development of adequate energy supplies. In recent years, taxes on the oil industry have been increasing dramatically. In 1975 income taxes took 55 cents out of every dollar of Phillips pretax income. In 1980 they took 67 cents."

During 1980 Phillips estimated their worldwide proved reserves of crude oil decreased 17%, while their natural gas reserves declined 12%. In the U.S., Phillips oil reserves were ". . . about the same as a year earlier." Phillips U.S. gas reserves dropped 6% during the year. Phillips drilled or participated in 36% more wells than in 1979 and produced more oil from mature fields; the company's total U.S. oil production was essentially the same as in 1979. "Phillips U.S. natural gas production was down 12 percent. . . . The decline reflected an industry trend caused primarily by reduced market demand. Phillips continues to be one of the largest U.S. natural gas liquids producers as output rose 6 percent. . . . An environmental suit delayed drilling in California's Santa Barbara Channel throughout most of 1980. By the end of the year, however, three drillships were in place and operating."

"In the United States, the company will continue to concentrate its petroleum exploration effort in Alaska, the Rocky Mountain Overthrust Belt, the Gulf of Mexico, California's Santa Barbara Channel and other areas of the Outer Continental Shelf. These are considered to be the most promising prospects for new, large domestic discoveries. . . . At the same time, Phillips intends to be an important force in developing other energy resources, primarily coal, geothermal and oil shale. These are the energy sources that will supplement petroleum as the world moves toward the 21st Century.

Phillips sees its production of petroleum and natural gas declining slightly in 1981, primarily because of anticipated lower overseas production. Phillips domestic oil production is expected to show a slight decrease, natural gas liquids will increase slightly and U.S. natural gas production is expected to continue its downward trend."

Shell, in 1980, added proved reserves equal to 137 percent of liquid and 113 percent of gas production. Oil additions from supplementary recovery added significantly to this performance. "We also remained among the top four majors in onshore seismic exploration, drilling and leasing. . . . Our oil and condensate production increased 8 percent over that of 1979. . . . In 1980 we began construction on (coal) mines in Wyoming and Illinois; continued planning for development of our lignite mines in Texas and Arkansas . . ."

"At year-end, we had 65 rigs engaged in domestic development operations — a 33-percent increase over 1979. In particular, we devoted large expenditures and substantial effort to oil and gas in the Gulf of Mexico; steam recovery of heavy oil in California's San Joaquin and Los Angeles Basins; and oil and gas development in eastern Montana, western North Dakota, and Michigan. In all, domestically, we drilled or participated in 1,110 wells onshore and offshore. Of these, 960 were successful, 825 oil wells and 135 gas wells. We also initiated 14 supplemental recovery projects (ones in which gas, water, steam, carbon dioxide, or chemicals are injected to obtain oil not recoverable through primary production techniques). And we announced plans to participate in a $2.3-billion oil recovery project using carbon dioxide."

"In 1980, we began modernizing our California refinery complexes to improve energy efficiency and increase our ability to refine heavier, high-sulfur crudes. This program will enable us to replace purchased light crude with heavier oil from our own California offshore and onshore fields. It will also enable us to upgrade high-sulfur residual fuel to premium light products."

"In the 1980s, the United States has the opportunity to make decisions and take actions that will make it more energy self-reliant and thereby reduce its heavy dependence on imported oil. Principally, this involves developing its own energy resources and using energy more wisely." Shell remarks about the progress in conservation and the fact that the new administration promises to stress marketplace economics. Chairman Bookout remarks that energy conservation and development of synfuels and other alternative energies are important, "But the key element is still development of conventional oil, gas and coal, for these must serve as the bridge to a wider range of energy sources in the future."

Principal near-term objectives include continuing profitable expansion of domestic exploration and development and strong R&D, including synfuels and use of CO_2 for EOR.

Standard of California (Chevron) projects an expenditure of $4.2 billion in 1981 for capital and exploration, highest in its history. Two-thirds will be invested in domestic activities. "The petroleum industry drilled 64,000 wells in the United States in 1980. This is an all-time high, and its attainment can be attributed, in large measure, to the phased decontrol of oil and natural gas prices."

"Chevron U.S.A. achieved significant successes in 1980 through a strong emphasis on exploration activity and further refinement of new technology. Investments for finding and developing domestic oil and gas reserves reached a high of $1.5 billion in 1980 — representing more than two-thirds of the Company's total worldwide expenditures for these activities . . . Recent technological advances played a key role in these results. Continued improvements and breakthroughs by Chevron Geosciences and Chevron Oil Field Research in seismic field recording and data processing techniques have marked significance for future operations."

"The Federal government controls about one-third of all the land area of the United States in addition to all the outer continental shelf beyond state jurisdiction. However, less than five percent of these waters has been leased for oil and gas exploration, and only two percent is under lease currently. By comparison, 40 percent of the rest of the Free World's shelf area is under lease, concession or exploratory contracts."

"It has been evident for some time that available crude oil is becoming heavier and poorer in quality. With the world's supply of light, easy-to-process crude gradually diminishing, foreign producers increasingly insist that we take a larger percentage of heavy high-sulfur oils. In light of this, the Company last year embarked upon the largest single industrial project in its history, a $1 billion modernization program at our Pascagoula, Mississippi, Refinery. When completed in 1983, this facility will be able to process large quantities of heavy crude . . . (and) convert heavier crude to a variety of light fuels, particularly jet and diesel."

Chevron is emphasizing geothermal, uranium and shale oil, in 1981 starting up a semiworks for retorting shale. This would be the first step in what is presently planned as the largest U.S. synthetic liquid fuel project at 100,000 b/d capacity, to be attained through modular expansion (100,000 b/d is the capacity of one medium-sized oil refinery).

Standard of Indiana (Amoco) — "Capital and exploration expenditures in 1980 came to a record $4.2 billion, an increase of 38 percent over 1979. United States spending totaled $2,858.6 million, 68 per cent of the worldwide total. Of this amount, $2,182.6 million was spent to find and develop domestic supplies of crude oil and natural gas, 40 per cent more than in 1979. . . . Our efforts in 1980 replaced 106 per cent of the crude and natural gas liquids we produced in the U.S., and 73 per cent of our natural gas production. Worldwide, we replaced 107 per cent of the crude oil and natural gas liquids we produced in 1980, and 125 per cent of our natural gas production."

"The Board of Directors has approved a capital and exploration budget of more than $5.1 billion for 1981. Seventy per cent of the budget will be spent in the U.S."

"For the U.S. as a whole, total energy consumption declined about 3 per cent from 1979 . . . we nevertheless continue to import about 40 per cent of our supply. . . . As a result of the 1980 election, there is evidence that stepped-up production will receive as much encouragement as conservation. Conservation continues to be important, but it alone cannot solve our energy dilemma."

"The industry's total domestic oil production is expected to decline by 1 to 2 per cent in 1981, while natural gas production may change slightly, depending on weather and the national rate of economic recovery. . . . Our company's domestic oil production is expected to decline about 5 per cent in 1981. For several years thereafter, production is expected to remain stable as oil from recent discoveries begins to flow. . . . In October 1980, the Canadian government announced its National Energy Program. The program is designed to favor Canadian companies and individuals to the disadvantage of foreign-owned companies such as Amoco Canada. The scale of our operations will be curtailed in 1981 because of this program."

"Standard continues to view its oversees investment as a means of increasing and diversifying its oil supply base. Foreign production should continue to make significant contributions to earnings."

Standard of Ohio (Sohio) " . . . owns the largest reserves and is now the largest producer of U.S. crude oil. . . . For the first time since production of crude oil from Prudhoe Bay began in 1977, the field operated for a full year at the maximum allowable rate of 1.5 million barrels per day. . . . In coming years, exploration for oil and gas will assert a dominant role in Sohio's picture. We plan to become a major factor in coal. And synthetic fuels, although longer-range, continue to be of interest to us."

"In line with our aggressive posture toward exploration and development of oil and gas, optimal recovery of our existing reserves in Alaska will remain one of Sohio's highest priorities. In fact, almost half of 1980's total capital expenditures were for this purpose, and we expect that $6.3 billion will be required in the next ten years for continued development of the Prudhoe Bay field."

"Sohio believes the use of coal as fuel under boilers will grow substantially over the remainder of this century. We feel that it makes far better sense to preserve oil and gas reserves for use as transportation and heating fuels. . . . Synthetic fuels such as those from shale, tar sands and coal continue to be important to Sohio and to the nation as a further source of potential energy for the future. However, in addition to the economic uncertainties of developing appropriate technologies in these areas, Sohio and others in our industry must cope with regulatory restrictions which are sometimes severe."

"The rate of flow from the Prudhoe Bay field, in which Sohio maintains a 53-percent working interest, is expected to remain at approximately the present level through the mid-1980s, providing an estimated average gross production of 1.5 million barrels per day. After that time, increasing gas and water production combined with falling pressure will result in some natural decline in production for the remainder of life of the field. . . . Sohio's average wellhead price for Alaska crude was $16.79 per barrel in 1980, compared with $10.72 in 1979. The average wellhead price for Sohio's crude oil exclusive of Alaska was $20.65 per barrel in 1980, up from $12.18 per barrel in 1979."

"During 1980, Sohio participated in seismic surveys totaling more than 700 crew weeks with an exploration staff which has grown to 330 people from only 60 at the beginning of 1978. . . . During 1980, Sohio participated in 38 exploration wells in the lower 48 states, compared with three in 1979. Of these 38 wells in which the company had working interests, ten were still in progress at year-end. Of the 28 wells completed, 12 were judged to be commercial."

" . . . after peaking in 1978, gasoline consumption fell 5 percent in 1979, and an additional 6.5-percent decline was recorded in 1980. As the consumption of gasoline continues to decline, Sohio has the flexibility to increase production of diesel and other fuels as their demand grows."

Sun comments that the improved economics of the oil and gas business invite strong participation, that coal will be a very significant energy source in the mid-1980s and beyond, and that other undeveloped energy sources will emerge in this decade. Sun pioneered in syncrude from tar sands, is actively developing geothermal resources, and is participating in oil shale development. Sun bought the domestic oil and gas properties of Texas Pacific Oil Company from Seagram for $2.3 billion and spent $673 million capital investment in exploring for and developing domestic oil and gas reserves in 1980, an increase of 76% over 1979.

"Sun plans to invest more than $250 million over the next three years for development of reserves on the Sun Texas producing properties. The newly acquired properties also contain significant amounts of carbon dioxide gas. This is a highly effective agent for enhanced crude oil recovery, and under proper conditions can be used in certain of Sun's West Texas properties. Also, a market is expected to develop for any excess carbon dioxide. . . . The number of net development wells drilled, for both oil and gas, will average 660 a year in the next three years, up from 423 in 1980."

Sun expects to increase its coal production from 11 million tons in 1980 to 17 million by 1983 and 30 million tons by 1990. In synthetics, Sun with its partners, Sohio and Phillips are updating feasibility studies for a 50,000 b/d shale oil plant by 1989. Net synthetic crude production from Athabaska oil sands averaged over 46,000 b/d for 1980, up nearly 10% over 1979.

Sun faces a major problem in its sand syncrude production. Canada originally granted Sun the world price for its entire production. However, beginning November 7, 1980, under its new laws, the Canadian Government determined that the sand production would receive only the same price as conventional crude oil, despite much higher costs in mining the oil sands. This reduced Sun's price from $32 per barrel to $14 per barrel, despite the fact that the only other plant operating will continue to receive the full price.

Texaco in 1980, like others, recorded a record year for earnings and a record year for investments. Also like others, Texaco expects to exceed this investment in 1981. Texaco's plans concentrate on five basic areas during the next five years:

- Selective, but increased exploration for oil and gas.
- Continued modernization of downstream facilities, with first priority in the United States. $1.4 billion has been completed, started or announced during the past two years. "These projects will allow the Company to use a wider range of crude oil feed-stocks, including heavy and high-sulfur grades, to produce high-quality products at more competitive costs."
- Continued petrochemical expansion.
- Emphasis on alternative energy where economically attractive.
- Nonenergy areas.

Outlook — Middle East stability is the key. Texaco is budgeting an all-time high of $4 billion in capital and exploratory expenditures in 1981, about 59% to exploration and production. Seismic activity is running about twice that of 1979, with further increases in 1981, drilling has been accelerated with the number of wildcat rigs nearly doubled during 1980.

Texaco shows dropping reserves in oil and gas during the past several years. It comments that the 1980 drop in natural gas came from a revised study of Louisiana, while improved recovery techniques increased the estimate for U.S. oil in 1980. Increased natural gas reserves in Europe during 1980 came from discoveries in Germany.

"Texaco's drilling program is beginning to show results. In 1980, 67 wildcat wells were completed, of which 11 were oil discoveries and 12 gas discoveries. Development drilling in 1980 included 931 gross development well completions a 33% increase over 1979." Texaco comments that Canada's new energy policy may adversely affect their investment plans in Canada.

Texaco maintains an active interest in aviation fuels, pointing out that it supplied about 16% of the U.S. market and about 11% of the world market.

Union reports, "In 1980, the company spent $1.7 billion for capital and exploration projects. Of this amount, nearly $1.3 billion was spent in the United States, principally on petroleum, geothermal energy, uranium mining and oil shale projects. For 1981, we plan to spend almost $2 billion on capital and exploration projects, more than triple our 1980 earnings. Seventy-seven percent of this — or more than $1.5 billion — will be for projects in the United States. The 15 percent increase in capital spending reflects planned higher oil and gas exploration and development activity, both domestic and overseas, and development of geothermal and oil shale resources."

"Union plans to participate in drilling more than 600 wells in the United States in 1981, an increase of nearly 20 percent over those drilled in 1980. For every dollar earned in 1980 the company paid $1.40 in income, property, severance, the so-called 'windfall profits' tax and other miscellaneous taxes. This is a total tax of $905.1 million." Regarding oil price decontrol — "Approximately 80 percent of the additional revenues received flow to government and 20 percent to the companies."

"While we as a company are moving ahead to develop additional energy reserves, our national energy goals are still too vague. In the last several years, our country has wavered in efforts to forge a national energy policy. We face two energy futures. We can choose to reduce our reliance on imported oil — and we have the energy resources to do so. Or we can muddle along, subject to the whims of exporting countries. Our nation has the energy resources we need and we are improving our energy efficiency. We have more undeveloped oil, more natural gas, more coal, more uranium and more geothermal energy than we have yet produced in the history of our nation. Development of these resources, plus alternative energy sources such as oil from shale and more electrical power generation, gives us the time for technological breakthroughs on renewable sources."

"Still required, however is broad appreciation of the fact that this nation can determine its energy future. To do so requires regulatory consistency and balanced environmental policy; greater reliance on the free market; broader access to public lands for energy exploration while preserving wilderness areas, and wider use of coal and nuclear power without sacrificing health and safety considerations."

"Higher prices, more efficient energy-consuming machines and greater dedication to the total conservation ethic already have resulted in a 19 percent drop in oil imports in 1980 from the prior year. With continued encouragement, this nation could stabilize or improve domestic oil and gas output. We could cut oil imports in half. We could double our use of coal. We could triple nuclear power by finishing plants that already have government permits."

"We could get synthetic fuels and renewable energy sources on a faster track. We could strengthen the dollar by keeping tens of billions of dollars that otherwise would be spent on foreign oil in the United States. We could make our personal life style more secure by providing assured energy for jobs, homes and cars. In short, we could strengthen both our military and our economic security."

"During 1980, Union increased its natural gas and geothermal reserves while crude oil and condensate reserves declined, principally as a result of deletion of 80 million barrels of Iranian reserves. Crude and condensate, natural gas and geothermal reserves, expressed in equivalent barrels of oil, amounted to 2.38 billion barrels, down less than 1/2 percent from 1979. The results of our intensive program to find new sources of oil and gas in the United States were encouraging. We had successes in wildcat drilling, in exploiting prior discoveries through the discovery of new zones and fault blocks and in augmenting reserves in long established fields."

"Exploration and development activities overseas were at a high level during 1980. Union participated in 30 exploratory wells and 22 development wells, with an additional six exploratory and three development wells drilling or testing at year's end. Fifty percent of the exploratory wells were successful. Oil discoveries were made in the Netherlands, Norway, the United Kingdom, and Indonesia. New gas discoveries were made in the central part of the Gulf of Thailand where Union holds substantial interests in five large blocks."

"In October, Prime Minister Trudeau announced a new energy policy and put in place an eight percent severance tax on all crude oil produced in Canada. Further, effective January 1, 1981, the tax is not a deductible expense for Canadian federal income tax purposes. As a result of this unbelievable taxation policy and other proposed provisions of the new federal budget and National Energy Program, Union of Canada is facing a drastic reduction in net earnings and cash flow. Exploration and production programs in Canada therefore have been reduced to an absolute minimum."

"Union Oil Company is the largest producer of geothermal energy in the world. It supplies steam for 1.2 million kilowatts of electrical generating capacity on-line in the United States and the Phillipines." Union has a half interest in The Geysers in northern California, the largest single geothermal operation in the world, at 746,000 kW; Union plans to open an additional 110,000 kW capacity in 1982 and another 100,000 kW in 1983. Union completed a 10,000 kW project in the Imperial Valley of California in 1980 and another 10,000 kW is scheduled to begin operation at the Salton Sea in 1982. Union calls the Imperial Valley the "Saudi Arabia" of the world's geothermal energy resources, capable of producing more than three million kW of electrical power. In cooperation with a public utility and the U.S. DOE, Union is developing the Baca project in New Mexico, where the first plant of 50,000 kW is scheduled for completion in late 1982, subject to permits.

"By far the largest and most important (alternative to oil and gas) resource to Union is oil shale. During 1980, we began work on a 50,000 barrel a day shale oil production facility in Colorado. This is the first major shale oil project to get underway in the country. The project is being planned in two phases. Phase I

will consist of a 12,500 ton per day mine and 10,000 barrel per day retort and upgrading plant to produce high quality, pipelinable syncrude which will be a premium feed-stock for any refinery. Completion of Phase I is scheduled for 1983. Phase II will entail additional mine, retort and upgrading capacity to bring the total production to 50,000 barrels a day of syncrude by 1988." 50,000 b/d is the capacity of one small refinery. U.S. aviation uses somewhat less than a million b/d of jet fuel. "We are proceeding with the expectation that the company will be able to enter into a products purchase contract with the Department of Energy for the full 10,000 barrel per day production of Phase I."

"A new combination hydrotreating and catalytic process was developed for upgrading crude shale oil to a high quality syncrude which will remain liquid at low pipeline temperatures. The syncrude is of such high quality that we are able to produce jet and diesel fuel by simple distillation."

Oil Industry Outlook

On the occasion of the annual meeting of the American Petroleum Institute in November 1981, Gene T. Kinney, Editor of ***The Oil and Gas Journal***[3.4] introduced their November 9 issue by noting that oilmen face a vastly different world from the one that existed ten years ago. "Consider international crude prices. Who could have imagined such a staggering increase during the decade? And who could have foreseen the nosedive in demand? The National Petroleum Council enlisting the best minds in the industry, overestimated 1980 oil consumption in the non-Communist world by almost 25 million b/d."

"Texaco's John K. McKinley dramatizes the enormous impact of past conservation: 'It is equivalent to two and a half times the recent daily production of Saudi Arabia.' Consultant John H. Lichtblau assesses the future effect: 'World oil demand will start recovering next year but will climb at a very slow rate and is unlikely to exceed the 1979 level of about 52 million b/d in this decade.'"

"Several of the chief executives see an end to shortages, barring some new political disruption. As a result of the slackening of demand and the rise in non-OPEC supply, Mobil's Rawleigh Warner Jr. believes the full OPEC capacity is not likely to be called on in the 1980s. Standard of California's George M. Keller goes beyond that: 'Socal is looking for a demand-constrained world market through the end of the century, resulting in a continuation of today's surplus in production capacity.' In the view of Shell's J.F. Brookout, the U.S. demand for oil peaked in 1978 at 17.8 million b/d and will decline to 15 million b/d by 1990.

"The opportunities for the U.S. industry are emphasized by Standard of Indiana's T.B. Redmond. He predicts '90,000 wells/year by 1985 and more than 100,000 wells/year throughout the decade of the 1990s.' Exxon's C.C. Garvin, calling today's glut transitory, believes the long-range energy problem remains basically the same. And he concludes — as we do — on this cautious note: 'It would be dangerous to allow today's euphoria to distract us from what needs to be done.'"

Other highlights from this "API Report" issue of the ***O&GJ*** follow. The coverage is much briefer here than in the oil company annual reports, in spite of the fact that the information is more timely, because the original is readily available and, for those interested in more context, each of the four editorials and the ten articles from industry is relatively short, averaging less than two pages apiece.

Robert T. Tippee, Senior Editor in "The Oil Surplus — a Fleeting Phenomenon?"[3.5] "The key change: oil and overall energy demand dramatically lower than predicted as recently as last year. In the U.S., oil consumption may have reached its historic peak in 1978. The reason: the demonstrated ability of rising prices to rein demand. Just as supply and demand respond to price, crude oil exporters have found that the reverse is also true. Even a cartel cannot sustain price levels that cause massive conservation and fuel switching.

"Here are highlights of recent forecasts of energy supply/demand through 2000 from key oil companies and industry analysts:

- Non-Communist energy demand will climb to 115-131 million b/d of oil equivalent in 1985 and 139-155 million b/d in 1990 from 95-100 million b/d at present. Demand in 2000 will be 139-172 million b/d of oil equivalent.
- Energy demand for developing nations will increase two to four times the rate of increase of industrial nation demand.
- Oil's share of non-Communist energy demand will fall to 30-40% by 2000 from about 50% in 1980 levels, but oil use in absolute terms will increase.
- Production from countries outside OPEC will increase.
- OPEC exports will be about even with or slightly less than 1978-80 levels, but oil demand by developing countries will increase, so OPEC production will have to increase during the 1990s.
- Non-Communist economic growth will average 2-3.5%/year.
- World crude prices will increase slightly faster than inflation.
- In the U.S., energy demand will increase, but the oil and gas share of total demand will decrease from about 70% in 1980 to about one-half in 2000. Oil's share of total demand will decrease to less than 30% in 2000 from nearly 50% at present.
- U.S. oil demand will average 14-15 million b/d in 1990, compared with about 17 million b/d in 1980. Forecasts of U.S. oil demand in 2000 range from less than 13 million b/d to 16 million b/d.
- The U.S. will continue to import substantial volumes of oil through 2000.
- Communist countries as a group may become net importers, but they won't put as much pressure on international crude markets as some analysts once thought.

"Texaco says, 'And, even with strict and enforceable production controls, it is doubtful that OPEC can maintain price escalation rates in excess of 2% per year.' Texaco points out price increases boost supply by stimulating drilling activity. But the effect is impossible to measure in the short term because of uncertainties about exploration results.'"

"Variations among forecasts hinge mostly on assumptions about price increases and their effects, economic growth, and chances for further major supply interruptions from Middle East and African producers. At one extreme edge of possibility, a crash in crude prices could reignite demand, snuff the drilling boom, and shatter economics of oil substitutes, creating new supply problems."

In an anonymous article, the ***O&GJ***[3.6] concludes that the oil industry will need to borrow funds in the 1980s because, largely due to exploration and development expansion, capital expenses will exceed earnings. Internal cash flow will provide 73% of industry funds. In an interesting aside, Exxon is noted to have remarked: "If economic growth rates, for example, were to vary by 0.5%/year from those projected here, energy demand could vary by about plus or minus 17 million b/d in 2000." That is equal to the entire U.S. petroleum consumption in 1980.

". . . (Sohio) projects U.S. energy demand increases averaging 1.25%/year through 2000, reaching 100 quadrillion BTU/year." This seems to have been the consensus of most analysts in the industry and government, but about six months earlier. Today the consensus would probably be lower, but 100 quads is a convenient figure to remember and use.

The same article adds "In short, says Davis (Gulf), "low oil prices would be popular with consumers and would stimulate economic growth. But low prices would sharply increase our dependence on foreign suppliers and would reduce our national security. Higher prices wouldn't make consumers happy, but they would stimulate domestic energy production and cut deeply into our appetite for foreign oil." "Already, Lichtblau points out, synfuel projects are being scrubbed or scaled down because of price moderation." Lichtblau also says, "This (the new price uncertainty) is why forecasting a supply and demand balance for 1990 is more difficult today than a year ago, when the direction of the oil price trajectory for the 1980s was accepted as a matter of faith."

C.C. Garvin Jr., Chairman and CEO, Exxon Corp. [37] — "The most striking development has been the decline in oil consumption around the world. Over the past 2 years, the combined consumption of the U.S., Europe, and Japan has fallen by 13%. . . . Since internationally traded oil is priced in dollars, and since the dollar has gained in value vis-a-vis other currencies during most of this year, foreign economies have been subjected to an even greater price shock than has the U.S.

"My conclusion is that while oil supplies, in the absence of a new Middle East crisis, should be comfortably available for some time to come, the immediate surplus is more likely to shrink than to grow." (Largely because surplus stocks have been drawn down). "Because the cost of carrying inventory at today's interest rates is so high (it's currently in the $8-10/bbl/year range), because importers have been reluctant to pay the high prices that some of the more hawkish oil exporters have been demanding, and because of the recent production cut by Saudi Arabia, we are now beginning to see a liquidation of this cushion." (Saudi Arabia) ". . . is a country with the latitude to vary its production significantly without harming its basic economic interests. . . . OPEC production levels of recent months . . . have fallen to about 20 million b/d from a previous high of almost 30 million b/d."

John M. McKinley, Chairman and CEO, Texaco, Inc. [38] — "As can be seen now in retrospect, incredibly cheap energy in the 1950s and 1960s — energy priced at far below its replacement cost — led to unsustainably rapid growth rate in consumption. Many industry experts felt that oil demand would continue to rise rapidly. A study by the National Petroleum Council in the early 1970s projected that free world demand would reach 73 million b/d in 1980 . . . this projection is almost 25 million b/d above 1980's actual level . . ."

"With considerable short-term excess in production capacity, Texaco expects real world crude oil prices to remain relatively stable over the near term, barring a new major supply disruption. . . . Texaco now projects that free world energy demand will increase at about 2.3%/year between 1980 and 2000. However, the switch to alternate fuels, primarily coal and nuclear worldwide and natural gas outside the U.S., will slow the increase in oil demand to only about 1% per year."

"In Texaco's judgment, petroleum demand in the U.S. peaked in 1979, and will remain relatively stable at about 16 or 17 million b/d through the end of the century. Increases in distillate and jet fuel demand are expected to offset declines in the demand for gasoline and residual fuel."

"When comparing crude oil price decontrol and natural gas price decontrol as presently scheduled, there is a decided difference. Under the Natural Gas Policy Act of 1978, which allows for gradual decontrol of natural gas prices, between 40% and 60% of all natural gas will continue to be permanently subject to some sort of government control. Moreover, natural gas is being sold in the U.S. under contracts that were made many years ago when prevailing prices were quite low. As a result, under current law and existing contracts, some natural gas may not reach equivalency with the world price levels of crude oil."

"Unfortunately, while the U.S. moves toward a more sensible energy policy, some of this country's closest allies are adopting counterproductive measures. Canada's new energy program, which discriminates against foreign companies, as well as its recent crude oil tax increases, has dampened exploration and production activity in its petroleum industry. The U.K.'s continued increases in tax burden have caused the delay, and perhaps even termination, of several important producing projects."

George M. Keller, Chairman, Standard Oil of California [39] — "Long-term, Socal is looking for a demand-constrained world market for oil through the end of the century — resulting in a likely continuation of today's surplus in production capacity. In our economists' view, crude demand is expected to grow, on average, by less than 1%/year through 2000. . . . We now expect (prices) to grow slightly faster than the rate of inflation. Here again, the forecasters are talking about a long-term average."

"Even if real energy prices — adjusted for inflation — increase no further in the foreseeable future, our economists feel it is clear that the upward price movements of 1979-80 will continue to promote conservation measures as old machines, plants, buildings, and vehicles are replaced by new, more efficient ones. The net long-term result should be a respite from the price surges of the 1970s, and this should permit the anticipated modest increase in oil demand to occur in the coming years without undue strain on existing supplies. (Socal expects) ". . . a demand-constrained market through the end of the century."

"Like energy supplies, energy prices will continue to be highly sensitive to unpredictable political events. Certainly unforeseen military or political events affecting the Middle East could drastically change today's picture. However, barring a protracted loss of a large supply element, world oil consumption through the end of the 20th Century seems likely to move in a relatively narrow range."

"The U.S. component of our forecast assumes an aggressive domestic energy development program to minimize American vulnerability to disruptions in world oil supplies. It also suggests the following course of action for the nation:

- Energy efficiency improvement must continue . . . high on the list of national priorities — even in times of surplus supply.
- Oil and gas exploration and production programs . . . must remain at high levels. More federal and state properties need to be made available for exploration.
- Natural gas regulations must be adapted to the realities of the marketplace.
- All alternative forms of energy must be developed to the full extent of their economic viability. Near term, these sources include especially coal and nuclear. Longer term, liquid synthetic fuels . . ."

Fred L. Hartley, Chairman and President, Union Oil Co. of California[3,10] — "In 1970, it took 62,000 BTU of energy to produce $1 of GNP. In 1980 the ratio had dropped to 55,000 BTU/GNP dollar. If this trend continues, it will take only 40,000 BTU of energy to produce $1 of GNP by the year 2000. . . . By putting our own house in order, America has made a major contribution toward stabilizing the world oil market. . . . Since 1980, following the start of phased decontrol of crude oil prices, U.S. oil production has held fairly steady, after years of decline. Natural gas production, which has had some price improvement, has also held steady. Thus, we not only began to use less, but also to produce a larger proportion of the oil and gas we use."

"While overall energy demand in the U.S. is expected to continue to increase through the rest of this century, oil and natural gas consumption will probably decline. We can now expect increased utilization of coal, nuclear, geothermal, hydro, and solar over the next two decades, as well as the beginning of the synthetic fuels industry — especially from oil shale."

"Federal lands are estimated to hold 37% of our undiscovered crude oil, 43% of our undiscovered natural gas, 40% of our demonstrated coal resources, 80% of our recoverable oil shale, and 95% of our tar sands. Yet, despite the promise these lands hold, about two-thirds are formally closed or restricted to mineral operations."

". . . America is still importing about 35% of its oil, and it will take a lot of effort to reduce that dependence substantially. We will continue to live with the threat of a serious disruption in world oil markets which could seriously impact our economy. While free world non-OPEC oil production has been increasing steadily, it is expected to slow in the late 1980s. Combined with rising demand, this slowdown will allow OPEC the chance to again raise prices in real terms. . . . The progress we have made in the past 2 years shows that increased energy security lies within our grasp."

"The pace of synthetic fuels development has picked up. For example, my own company will start operating the first commercial superquality synthetic crude oil plant utilizing oil shale rock by summer 1983. This $500 million, 10,000 b/d plant is a 100% private investment, and the taxpayers are not involved in funding or guaranteeing loans to build the project."

William C. Douce, President and CEO, Phillips Petroleum Co.[3,11] — "Public apathy diminishes enthusiasm for efforts to find more oil and gas. It reduces pressure to conserve. It lowers the priority for developing synthetic fuels. It slows the effort to reinstill public confidence in nuclear power. And it blunts long-term programs to tap the energy potential of the sun. With a surplus of petroleum in the marketplace, the most recent polls conclude that only one in 10 people considers energy to be one of the two most pressing problems in the country."

"Worldwide petroleum production is now approaching 45 million b/d, 2 million bbl above daily consumption. But the surplus is fragile and could be turned to scarcity overnight by decisions in Middle East capitals to cut production or reduce export levels."

"Although oil production in the U.S. has probably passed its peak and will decline gradually, petroleum will remain the dominant energy source through the rest of this century. . . . There is more domestic oil and gas to be found — possibly more than has been found to date — and rising prices will assure that it is discovered and brought to market. . . . The opening of more federal owned lands for exploration is a positive step to boosting domestic production."

"The energy outlook for the 1980s will continue to be plagued with price and supply uncertainties stemming from international tensions. Even in the face of these uncertainties, the oil industry will react to longer-term incentives and persevere in its efforts to produce more oil and gas — both at home and abroad."

Jerry McAfee, Chairman and CEO, Gulf Oil Corp.[3,12] — "Several years ago the chairman of a major, overseas-based oil company remarked that, in energy matters, the most important nation in the world was not Saudi Arabia but the U.S. His point was that, notwithstanding the massive oil reserves of the Saudis, the U.S. exerted the most influence on energy matters because of our position as the free world's largest producer and consumer of energy."

"Among energy experts, there are basically two views about today's surplus of crude oil. On the one hand, we have the optimists, who believe that the situation reflects underlying structural changes in petroleum markets and consequently see a very favorable outlook for the consuming nations. On the other hand, we have the pessimists, who contend that what appears to be a market change is really nothing more than a 'family feud' among Organization of Petroleum Exporting Countries members."

"Of course, in a strict sense, the discussion about oil gluts masks a fundamental reality — just as did the talk in the 1970s about oil 'shortages.' In fact, at no time since World War II has the world had a physical shortage of oil, with less capacity to produce than demand required. Instead, we have experienced the willingness of certain exporting nations to withhold available oil, resulting in occasional shortfalls of supply."

"After all, OPEC does control three-quarters of the world's known deposits of petroleum. . . . If Saudi exports dried up, they could not be made up fully from surplus productive capacity in other nations. . . . barring a massive disruption of Saudi exports, it is doubtful that OPEC would cut production much lower than current levels of less than 22 million b/d. In order to meet the financial and development needs of its member states, OPEC collectively must produce some 21 million b/d, while as recently as 1979 they produced more than 31 million b/d. Thus, at this point, OPEC does not enjoy nearly the latitude to reduce production that it once enjoyed. Moreover, as the recent spate of price-cutting by petroleum exporters indicates, many OPEC nations want to increase their production."

"In fact, OPEC's fundamental problem — slackening of demand for its product — has been generated not so much by the policies of the Saudis as by the workings of the marketplace. The rapid decline in demand has taken most observers — including those in OPEC — by surprise. . . . it appears that the switch from oil to other fuels has only begun. . . . Given these realities, it seems evident that Saudi Arabia clings to its current course mainly because of economic reasons. The Saudis appear keenly aware that OPEC may have taken the price of crude oil up so far that energy efficiency and fuel-switching could irreversibly limit future demand for oil. . . . In other words, the Saudis don't want to be stuck with a 60-year supply of a commodity that history has passed by."

"In addition, the moves in recent years to market pricing have produced a stunning supply-side response in the U.S. Spurred by higher prices, U.S. well completions this year are expected to top 77,000 — nearly 30% more than last year's record total. . . . Although the decline in production continues, it has been cut to only one-sixth the rate of decline experienced in the 1970s. Gulf's economists are now predicting that industry reserve additions may soon equal production, a development that

augurs well for keeping production at healthy levels. . . . I have no doubt that we can reach the goal of reducing oil imports to 4 million b/d — or less — by 1990. After all, with imports having decreased nearly 2.5 million b/d in the past 2 years, we are already more than halfway to our goal."

"Unfortunately, the U.S. has not been able to give up completely its national habit of interfering with the workings of the marketplace. For example, the Natural Gas Policy Act, although it did contain some improvements over previous policy, unfortunately continued controls on some categories of natural gas. In the case of domestic crude oil, the 'windfall profits' tax is a triumph of politics and prejudice over logic and economics. We estimate that in 1981 that excise tax will siphon off from Gulf Oil Corp. about $1.1 billion — more than 90 million/month."

T.B. Redmond, Vice-President, Planning and Economics, Standard Oil Co. of Indiana(3-13) — "We expect economic growth in the free world to year 2000 to average about 3.5%/year and population growth to average about 2%/year. For almost every country, the GNP growth rate will exceed the population growth rate, implying an improving standard of living. Free world energy demand growth to 2000 is expected to average about 2%/year — significantly lower than the economic growth. Still, energy demand will increase from the equivalent of 94 million b/d of oil in 1980 to 139 million b/d in 2000. The increase, 45 million b/d, is about the same as the expected free world oil consumption this year."

"The oil consumption of industrial nations dropped to 38 million b/d in 1980. Partly due to the economic slowdown, it is forecast to decline another 3 million b/d this year. Even after some near-term increase as economic activity picks up again, we expect a further reduction to 33 million b/d by 2000. U.S. oil consumption should decline from 16 million b/d of crude oil equivalent in 1980 to 15 million b/d in 1981 and 13 million b/d in 2000."

"In the context of such modest oil demand growth, we believe the oil supply situation should be fairly comfortable for the balance of this century. . . . demand for OPEC oil should be about 25 million b/d in 2000, of which OPEC domestic consumption will account for 7 million b/d. OPEC oil exports, which peaked in 1973 at almost 30 million b/d, would be down to about 18 million b/d in 2000, a figure last seen in 1968."

"U.S. natural gas consumption will remain essentially flat over the next 20 years, but in foreign areas it will increase significantly. The OPEC countries have prolific resources of natural gas, and these will be increasingly utilized in the local as well as export markets. . . . Coal will contribute the largest portion of the free world energy consumption growth, and its share of total energy will increase from 19% currently to 25% by 2000. Nearly 40% of the coal growth will be in the U.S. where coal consumption is expected to double from 7 million b/d of crude oil equivalent at present to 14 million b/d by the end of the century. Electric utilities will account for most of this increase."

Although free world nuclear power growth has been moderating for several years, . . . "it is expected to have the fastest growth rate of any energy source in the free world, increasing from 3 million b/d of oil equivalent in 1980 to almost 11 million b/d of oil equivalent at the end of the century. Its share of energy will increase from 3% in 1980 to 8% in 2000. . . . Hydropower development is relatively mature in the developed countries where little growth is forecast. However, in many of the developing countries, especially in Latin America, many suitable sites are still available; therefore significant growth is expected. Other renewable sources such as solar will begin to make small contributions in the 1990s, but they are not expected to provide major sources of energy until the next century."

"This outlook implies that the next 20 years will be a period of great opportunity for our industry. We believe the size of hydrocarbon deposits in the U.S. and its offshore is large. Also, there are large amounts of discovered oil, the development of which lies beyond the capabilities of most contemporary production methods."

John H. Lichtblau, President, Petroleum Industry Research Foundation, Inc.(3-14) — "To get a measure of the hazardousness of long term oil price forecasts, one only needs to look at the 10-year predictions made in 1970. None of the experts came even remotely close to the actual world price of last year. Nor did they do much better on supply and demand projections."

"We can see some structural changes in the marketplace which should make the 1980s very different from the 1970s. But to guess at the specific price in 1990 is still quite hazardous. Market trends in the 1960s were such that a substantial increase in the real price of oil would have been inevitable even without the Organization of Petroleum Exporting Countries from the mid-1970s on. The sustained growth rate in world oil demand at the pre-1973 price level was simply too fast relative to physically available supply and thus had to be substantially curtailed by means of higher prices to restore a market equilibrium."

"By 1978, after the price increases of 1973-74 had eroded somewhat in real terms, oil demand began to rise again at a rate which, if continued, would have led to supply tightness within 5-6 years. Thus, by the early 1980s a further real price increase to balance supply and demand would have been required even in the absence of the Iranian revolution."

"There is a debate over what part of the decline is cyclical and what part is structural. The cyclical part is ephemeral and will be reversed once the industrial economies of the world recover from their present slump which is now expected in the second half of 1982. The structural changes underlying the demand reduction are of course more enduring since they reflect economically motivated trends to conserve oil, use it more efficiently, and substitute other fuels for it. In the short run these trends are not readily reversible nor even arrestable." The cyclical component has been a significant part of the recent drop in demand as inventories have been decreased. But recovery in demand will " . . . be strongly tempered by a continuation of the structural downward trend in oil consumption."

" . . . world oil demand will start recovering next year but will climb at a very slow rate and is unlikely to exceed the 1979 level of about 52 million b/d in this decade. Meanwhile, the existing production constraints resulting from the Iranian-Iraqi war can be expected to end, freeing substantial additional OPEC supplies for export. Also, non-OPEC supplies will continue to increase, perhaps at an annual growth rate of about 500,000 b/d to 1985 and somewhat less thereafter."

"Thus, market conditions do not require an increase in the real price of crude oil for the next 7-8 years to balance supply and demand, since throughout this period there will be excess producing capacity. In fact, for the next 4 years the magnitude of the excess will be such that on the basis of market conditions the real world oil price should decline from its present level. This is in sharp contrast to the 1970s when market conditions, as we have seen, put upward pressure on prices."

"Since no OPEC member is attempting to sell below the floor price, the organization remains effective, although its upward price mobility is severely curtailed by market forces. . . . With

13 million b/d of readily producible OPEC oil overhanging the market, some members may succumb to the temptation to sell more oil by offering hidden or open discounts to their customers. Once this process spreads it would rapidly undermine OPEC's floor price defense and cause prices to tumble."

"Probably OPEC's long term survival will depend on its ability to maintain its crude oil output between 22 million b/d and 28 million b/d. As of now, it seems that an OPEC production level within this band is more likely during the 1980s than one below or above it."

J.F. Bookout, President, Shell Oil Co.(3-15) "The 1970s proved to be a nightmare for those given to forecasting — economists, politicians, and oil people."

"Since 1979 and OPEC's further price increases and the decontrol of domestic oil prices, the decoupling (between energy and GNP) is proceeding apace. Total energy use is declining somewhat, and oil use has been declining 4-5%/year, these last years. Before 1978, oil was penetrating the fuels market; since then it has been backed out. . . . Shell expects these trends, including the 'backing out' of oil from the energy supply mix, to continue. By 1990, we expect total U.S. energy demand to have grown by less than 1%/year."

"We believe demand for oil peaked in 1978 at 18.9 million b/d and that it will decline to approximately 16.3 million b/d by 1990. Oil will have dropped from 47% of our primary energy mix in 1978 to about 37% by 1990."

"We are learning that oil-consuming nations have leverage in the producing countries/consuming countries' 'contract.' . . . we must continue to practice conservation. We must encourage switching from oil to other fuels. And we must develop our own energy supplies. . . . In our opinion, striving to hold present domestic oil production levels requires accelerated federal leasing and greater enhanced oil recovery from existing oil fields and continued constructive public policy. . . . The decline of U.S. oil and natural gas liquids production has now been slowed, because of the greatly accelerated drilling activity to about 1%/year."

"It is interesting to note that while energy began to be used more efficiently after 1973, the backing out of oil in U.S. fuels markets only started after the 1979 international oil price hikes and after domestic oil price decontrol was started."

Rawleigh Warner Jr., Chairman, Mobil Oil Corp.(3-16) "Now the industrialized world is in the process of assessing the effects on their economies of the events of the past few years. The process of adjustment reflected in inflation and real economic growth is far from complete."

"In reality, the full impact of the 1979 oil shock has not yet been translated through the world's economy, for we have not been in a 'normal' situation for some years. Nevertheless, we have seen some significant changes that have long-term implications for our industry. The most important has been the marked decline in free world oil consumption since 1979. Several factors have caused this. The importance and permanence of each will be revealed with time. They are:

- Price-induced conservation.
- Fuel-switching for a new energy source mix.
- Widespread recession, primarily in industrialized nations."

"With this background, let us now examine the price and supply picture for the rest of the decade. On the supply side, we see the 1980s marked by moderation in crude oil demand. In addition, oil supplies from non-OPEC producing areas have increased. One result of these twin factors will be that the full OPEC capacity is not likely to be called on . . . oil consumption worldwide may be more affected by reduced demand growth than by tight supply for the next several years."

"The U.S. will have to increase production of its domestic energy supplies. That's the price of regaining a reasonable, feasible degree of energy security. It's unlikely that the U.S. will in the 1980s become entirely self-sufficient. That would be prohibitively expensive and unnecessary."

"Nuclear energy is one way we can reduce our dependence on fossil fuels, and nuclear fuel is more inflation-proof than fossil fuels. Our use of nuclear energy to generate electricity can be substantially increased, with safety, provided the issue can be taken out of the political and emotional arenas, and returned to the scientific arena — where it belongs."

1982 Update

According to 1981 annual reports from most of the oil companies, as might have been expected, the conclusions on exploration and production capacity developments during the year are variable. Some show successes and optimism; some show declines in reserves and are cautious about future production, particularly domestic. In view of the declining petroleum market during the year and particularly curtailed refinery activity, a cautious report to stockholders would seem appropriate. In a depressed market, it is questionable whether new finds should be publicized.

While current news reports declining exploration activity, a large percentage of the recent decline is from independent operators. According to their reports, the majors appear to be forging ahead with their development plants. But, it is also true that independent operators account for a high percentage of new wells brought in. The independents are important in developing new oil and gas production capacity.

Excepts from representative 1981 annual reports are included here to provide a sample of the situation. The ***Atlantic Richfield*** report is typical in describing the general economic climate and petroleum market situation. "Final decontrol of domestic oil prices in January (1981) greatly changed the environment for Atlantic Richfield and the oil industry, restoring competition to the marketplace and proving there is more elasticity in oil demand than expected. Immediately following decontrol, domestic crude prices rose to world market levels, which then fell within weeks in the face of declining demand. Petroleum product consumption in the U.S. dropped to its lowest level since 1973, and most forecasters believe the decline will continue. Meanwhile, the recession dampened the general business environment and thus earnings . . ."

". . . For Atlantic Richfield, the highlight of the year was the start up of the Kuparuk River oil field on the North Slope of Alaska in December, three months ahead of schedule. Production rates of 80,000 barrels a day are expected to grow dramatically and could reach 250,000 barrels a day by the late 1980s . . . With the addition of Kuparuk, the Company expects to be one of the few companies to maintain domestic crude oil production at current rates through much of this decade.

"Management affirmed its commitment to a more vigorous domestic oil and gas exploration program by forming ARCO Exploration Company in 1981. The Company invested $1 billion, out of a total capital program of $4.1 billion, in domestic exploration during the year, a record for Atlantic Richfield. These efforts are building what we believe to be an attractive portfolio of high-potential domestic prospects for the Company. Another $1.3 billion in capital investment went for domestic oil and gas production

"The Company will continue to invest heavily in these activities in 1982. A total capital program of $5 billion is planned, including $3.1 billion for domestic oil and gas exploration and development. The Company's international oil and gas program is also expanding, with $250 million targeted for these efforts in 1982."

Conoco (DuPont) — "Capital expenditures for petroleum exploration and production totaled a record $1.2 billion for the full-year 1981. Approximately two-thirds of these outlays were made in the United States, reflecting the company's emphasis on finding and developing secure petroleum supplies, and slowing or reversing the rate of decline in domestic crude oil and natural gas production."

"Future levels of domestic petroleum production will depend in large measure on the success of Conoco's exploration activities and on progress made in the development of economic methods of enhanced oil recovery."

Exxon — "As a result of an increase in gas reserves, Exxon's combined oil and gas reserves in the United States showed an increase for the first time in more than a decade. . . . Additions were particularly significant in the lower 48 states, where they exceeded production by 20 percent."

"Exploration drilling on Exxon USA's prospects onshore and offshore continued at the highest levels since the mid-1960s. The company made two significant natural gas discoveries in the overthrust area of southwestern Wyoming, and participated in several gas finds in Louisiana, Texas and Oklahoma. Exploration drilling also confirmed commercial quantities of oil and gas at Pescado, an earlier discovery off southern California."

Exxon goes on to headline, "European Exploration Efforts Led to Gas Discoveries in Norway, Oil Find Confirmed in Columbia, Onshore Gas Find Made in Thailand, and More Exploration Acreage Acquired in the U.S. Offshore and in Frontier Areas Abroad."

Gulf — "In 1981, operating earnings for Gulf Oil Exploration and Production Company increased 33 percent to $1.8 billion, with over three-fourths generated in the United States. The principal contributing factors were higher crude oil and natural gas prices, which also spurred record exploration and drilling activity. With greater incentives and higher cash flow, Gulf increased capital and exploration expenditures for oil and gas projects by 35 percent to $2.4 billion, and like earnings, over three-fourths was spent in the U.S.

"In 1982, the search for new reserves and the development of previous discoveries will require a similar level of investment as greater attention is placed in frontier areas. To meet the long-term expectations of of its shareholders, Gulf's primary goal is to minimize, and as quickly as possible, reverse the decline in its U.S. reserve and production levels."

". . . Despite this increase in drilling activity, production continued to outpace reserve additions."

Mobil — "Mobil continued to seek out and develop new supplies of oil and natural gas to meet future needs, with exploration and producing expenditures of $2.9 billion, the highest to date.

Promising new discoveries were made in Europe and Africa. Evaluation continued of earlier finds in Mobile Bay, off the coast of Alabama; in the Grand Banks and Sable Island areas of the Canadian Atlantic, and in Germany."

"Mobil is preparing for increased hydrocarbon production from its reserves in the Gulf of Mexico and the North Sea. . . . Final terms are being negotiated for our participation in a pipeline that will transport carbon dioxide from Mobil reserves in southwest Colorado to west Texas. Construction is scheduled to begin this year. The carbon dioxide will be used to increase oil production."

Occidental — "The Oil and Gas Division is proceeding with its most expansive exploration program ever. The Natural Gas Policy Act of 1978 and decontrol of domestic crude oil in 1981 substantially improved U.S. exploration and development economics."

". . . Overseas, we have active programs in 15 countries, nine of which began operations in 1980 or 1981. These stepped-up efforts, which began in 1978, are now beginning to show results."

Phillips — "Phillips estimated worldwide proved reserves of crude oil, condensate and natural gas liquids decreased 10 percent to 916 million barrels. Worldwide natural gas reserves totalled 6.77 trillion cubic feet, about the same as last year.

"Year-end estimates of proved reserves are based on then current reservoir information, technology and economics. Such reserves, however, cannot be measured precisely. Adjustments are made to reserve estimates to reflect changes in economic conditions, results of drilling and production and technical re-evaluation of reservoirs."

Shell — "We believe we remained the leading major oil company in replacing domestic oil and gas production over the last eight years. In 1981, we added proved reserves to 98 percent of U.S. natural gas production and 65 percent of U.S. crude oil and other liquids production.

"We also continued to rank among the top majors in domestic seismic exploration, drilling and leasing. We are active in some 50 domestic geologic 'plays' and participated in discovering 24 oil and gas fields in the United States.

"In all, we drilled or participated in a total of 1,560 exploration and development wells in 1981, more than in any year in our Company's history. . . . We also remained an industry leader in supplemental oil recovery — particularly in steam injection to increase production in our heavy oil fields in California. Preparations continued for major carbon dioxide injection programs to increase significantly oil recovery from existing fields in the West Texas/southeast New Mexico and Mississippi/Louisiana areas."

Standard Oil of Indiana (Amoco) — "At year end we held 41.3 million net acres of exploration and production rights — the most in the industry — and owned 20,615 net oil and gas wells on 2.9 million net producing acres. Crude oil production declined 6 percent, and natural gas liquids volume decreased 5 percent. Our estimated U.S. net crude oil and natural gas liquids reserves were 1,674 million barrels at year end, compared to 1,663 million barrels at the close of 1980. Exploration and development drilling and revisions to previous estimates added 170 million barrels, replacing 107 percent of our total U.S. liquids output of 159 million barrels in 1981.

". . . Our estimated U.S. net proved reserves of natural gas were 8,857 billion cubic feet at year end, compared with 8,434 billion cubic feet a year earlier."

Standard Oil of Ohio (Sohio) — "Over the next ten years, the company's planned investment of about $30 billions in dollars of the day for exploration and production will draw largely on cash from Alaska. This amount, half of Sohio's planned capital investments for the next decade, will be used to carry out a basic strategy for exploration and production that involves four objectives:

- "to optimize production of Prudhoe Bay field reserves;
- to develop recently discovered reserves on the North Slope of Alaska;
- to explore for, find, and develop new reserves in Alaska and other geologic frontiers of North America; and
- to apply the latest technologies in the search for and development of these reserves."

Texaco — "Texaco is placing its major emphasis on exploration and producing, the area of the business that offers the greatest potential for profit. These activities are concentrated in the United States and other politically secure areas where there are prospects for reasonable returns.

"Since 1979, worldwide capital and exploratory expenditures have nearly doubled, with the largest portion allocated to exploration and producing investments . . . 69% was spent for finding and producing oil and gas.

". . . In 1981, the Company participated in 504 gross exploratory wells around the world — more than two-and-one-half times the 188 drilled in 1979.

". . . Texaco's aggressive program of exploration and production in the United States has been noticeably effective. Liquids production, which had traced a declining curve in recent years, showed a reduction in rate of decline in 1981. There is no assurance that this improved trend will continue, but these results do justify the expansion and search for new reserves."

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Chapter 4

U.S. Petroleum Forecasting

Board Room Briefing No. 4

1. It is axiomatic that U.S. petroleum is a finite resource which will finally become uneconomic for fuels when depletion leads to much higher production costs in the future. The question is whether, neglecting international interruptions in oil supply, prices will increase gradually or whether they will surge strongly, and when.

2. U.S. oil discovery and production data cover a period of over a hundred years. The U.S. has been explored and drilled far more than any area in the world. If petroleum production experience for any part of the world can be assessed and forecast with confidence, the best results should be obtained for the U.S.

3. In 1962, statistical analysis of U.S. oil discovery and production data indicated that the peak of U.S. production would occur in about 1970. If experience followed the curve as the data indicated, U.S. production would decrease irretrievably beyond 1970.

4. Historically, U.S. production did peak in 1970, while subsequent discovery and production data continue to follow the mathematical trends derived from the historical data. (There was one excursion in discovery, Prudhoe Bay, Alaska, in 1970, but it did not alone alter the trend.)

5. Many forecasters and geologists conclude that this analysis forecasts the realistic and inevitable exhaustion of U.S. oil. In turn, the analysis sets a firm ceiling on the amount of oil that can be recovered in the U.S. and also sets a timetable for its exhaustion. Since, in this concept, final depletion is already in process, the long trend for U.S. oil prices must be to inexorably accelerate upward.

6. Many other forecasters now, particularly economists, believe that the future supply of oil is sufficient, short- to mid-term, such that the total amount is of no real consequence. They see the present demand/supply balance simply stretching out in time, with prices rising as necessary to provide the balance. Due to the unprecedented price rises in 1973-74 and 1979, they expect that much more oil will now be found and produced. Other constraints such as taxes, federal land leases, regulations and so on, are viewed as restraints on production, rather than physical depletion.

7. Energy conservation both in the United States and in the world, has been much more effective than even optimistic expectations. As a result, world demand is now less than world production capacity. Production has been curtailed by Saudi Arabia accordingly. The margin between supply and demand is still narrow, but conservation develops inertia and demand should drop further, even without price increases.

8. Oil companies' views about new finds and development are optimistic. Certainly exploration is proceeding at an unprecedented pace and plans are for greater expansion in the future. Many believe that success in finding oil and gas is limited only by the incentive.

9. Establishment of confirmed reserves (by seismic exploration and drilling) is expensive. An unproduced inventory bears interest costs and may be taxed. Institutional factors of this type discourage exploration and finding of oil, as well as listing of finds when they are made.

10. Many oil forecasters and oil managers feel strongly that the limit on U.S. production now is placed by the political will to produce. That is, regulations, restrictions on lands, tax structure and the like, control production more than other factors.

Introduction

The earth's central core is generally agreed to be molten nickel/iron. If, instead, it were prime crude oil, man's liquid-fuel dilemma would not be improved without some technical or economic breakthrough we cannot imagine now. If that fictitious "oil core" could be tapped with today's technology, which it could not, the oil produced would have to compete on today's market with coal, natural gas, shale, peat, geothermal, nuclear, solar, biomass, et cetera. It could not; the cost of drilling and lifting it would be too high per barrel.

In that sense, the supply and depletion of domestic petroleum in the U.S. has little bearing on our long-term future. The time will inevitably arrive when no oil in the U.S. can be produced at costs competitive with other available energy sources. At that point it doesn't matter whether there is still oil under U.S. land or not; it might be as uneconomical to reach as trying to mine the iron core. So the question is not how much petroleum reserve we have, but whether we are presently at or nearing the point where our production costs will become uncompetitive.

This question is affected by whether our economically competitive oil production is in its early stages or whether it has already passed its peak into a regime of inevitable decline. If it is already in decline, we must expect that domestically-produced costs will rise henceforth on an accelerating scale and that the rest of the world, not only OPEC, will escalate their oil prices accordingly.

The question must be answered only in gross terms. Are we at that point now or do we have one or two generations, or more, before our fuel transition from petroleum is forced upon us? It may be surprising that the answer today is not known with assurance, even in gross terms. In fact, we are in the midst of a

debate comparable to the astronomers' arguments between the geocentric versus the heliocentric concept of the solar system or, in our generation, the argument between the hydrogen nuclear cycle versus the helium nuclear cycle in our sun.

Oil Resource Forecasting

Washington Meeting

In the summer of 1980, the Department of Energy and the National Bureau of Standards sponsored a symposium on oil and gas supply modeling in Washington.[4-1] It was attended by 40-50 people. Although some attendees were from oil production organizations, most appeared to be from universities, government offices and data-processing contractors. Material presented and the discussions fell into three categories:

1. About 75% of the activity was on conventional oil-forecasting modeling concepts and variations in modeling techniques, input geological data, oil drilling and production statistics, and modeling results.
2. About 15% was concerned with the fact that modeling inherently assumes the future must be deduced from the past.
3. The remaining 10% of activity had concluded that the future will not be like the past, emphasizing that effects of economics, regulations, taxes and other sociological conditions could affect production as much as the geology and engineering.

Formal petroleum forecasts in the past have been based on geological data and mathematical analyses to show what might be expected in the future. For convenience, this is called the physical approach.

A newer approach is based on market considerations. Basically, its concern is with supply and demand. But it also recognizes that supply/demand balance in the market is affected by a host of other institutional, political and sociological factors, the most direct of these being the price of crude oil and other forms of energy. For convenience, this is called the market approach.

The physical approach acknowledges that the price of crude oil will have some effect on its final production. But it regards the effect of price as having far less influence than the earth's physical supply of hydrocarbons and the effect of scarcity on production rates.

In turn, the market approach acknowledges that prices will inevitably rise as oil becomes increasingly scarce. But market forecasters are generally convinced that past history cannot project future finds and production, since future economic conditions need not follow the policies and conditions of the past.

At the meeting, it appeared that the physical forecasters were primarily geologists and mathematicians; the market forecasters were apparently economists and business analysts. The geologists outnumbered the economists. The differences did not really surface until most of the papers were presented (at least, so it seemed to a novice like the author), but the discussions became increasingly forceful.

The three-day meeting ended without any seeming compromise or closing of the gap. Discussion emphasized more the differences between the two approaches than their similarities. Beside the author, some of the other attendees appeared to be encountering this issue for the first time.

Houston Meeting

About nine months later, a conference on crude oil forecasting was held in Houston.[4-2] Although the sponsor charged a fee and the speakers were largely from oil consulting and market-projection companies, surprisingly, a large proportion of the large audience of 150 or more appeared to be from organizations already engaged in or directly concerned with oil production. One might have thought they had already fully developed their philosophies and techniques for oil forecasting. Where the Washington meeting was reflective and scholastic, this meeting was as dynamic and pragmatic as the stock exchange.

There was virtually no discussion on the geological resource of oil in the U.S.; this meeting was concerned with supply and demand: prices, costs, world supply, political policies (such as the new policy emerging in Canada), OPEC operations, Communist interests, federal regulations, domestic drilling and demand, windfall profits taxes, and policies of the new Administration. Predictions were all based on supply and demand, with emphasis on demand.

In fact, the Washington meeting could be said to have been preoccupied with physical supply; this Houston meeting was equally preoccupied with demand and its interaction with prices. This may have been because the drop in demand was beginning to be seen and because demand at that time was in extremely delicate balance with supply. And it was ***rate*** of supply which concerned this group, not the total amount of resource available.

It also may be fair to add that the Washington meeting probably was concerned more with mid- to long-term forecasting, ten to fifty years in the future. The Houston meeting appeared more occupied with the next three to five years, possibly out to ten years. Nevertheless, at Houston the longer-term concerns were still with demand/supply, not with physical limitations.

One oil planner who spoke at Houston did acknowledge the physical approach. He observed that geologists and economists are not only answering questions from two entirely different points of view, they are answering two different questions. The geologist is concerned with "what is there," while the economist is interested in "what should be produced." He went on to observe that, while neither approach is "wrong," both over-emphasize the influence of their factors, while they practically ignore the validity of the other's.

While the "ultimate" supply is not infinite, as economists effectively assume for convenience, neither can the source supply be projected entirely from past production statistics. This speaker concluded that taxes and regulations predominate at present. And there is no historical experience with either the present market or political conditions. He would not hazard a guess about future political and sociological conditions, while the subject of taxes is in active debate.

From more than a hundred years of U.S. production, gargantuan amounts of physical data have been recorded. The analysis of these data has been highly professional and the results are fairly awesome. As a background for approaching the future and assessing the relative influences of these physical data, the classical or statistical approach to oil resource forecasting will be reviewed briefly. Further discussion will be found in Volume 2 and in the references provided.

Physical Oil Resources

It is interesting that, before the turn of the 20th Century there had already been several alarms that U.S. petroleum supplies might be running out. At the time of the Great White Fleet, the U.S. acquired lands for the Naval Petroleum Reserve, which it still holds today. Other alarms occurred into the 1920s. But the depression of the '30s and improved exploration and development methods, together with significant petroleum finds around the globe, nearly erased concern about petroleum depletion for some time.

World War II was "fought with U.S. oil," but there was no immediate concern about supplies even then, and the U.S. remained the largest petroleum producer and exporter in the world. Toward the end of the '50s, the question of depletion and ultimate U.S. (and world) resources regained interest. An Energy Resources Study was established by the National Academy of Sciences, National Research Council, chaired by Dr. M. King Hubbert, of Shell Oil Research and later of the U.S. Geological Survey. The report, published in 1962,[4-3] was addressed to the NAS-NRC Committee on Natural Resources and was concerned with all types of energy. Based on extensive earlier work by Hubbert, it was more than a landmark report; it was a watershed.

Since that time, serious discussions of physical depletion have referenced Dr. Hubbert's work either directly or indirectly: technical reports, articles in professional publications, popular discussions, textbooks, encyclopedias. As recently as late 1981, Dr. Hubbert received the Vetlesen Prize, awarded each year from Norway for the world's outstanding achievement in earth sciences (which are not included in the Nobel Prize categories). Some encyclopedias,[4-4,4-5] for example, have either had the appropriate section written by Dr. Hubbert or have included a thumbnail account of his resource depletion theory and its derivation.

His derivation by statistical analysis is both impressive and elegant. It applies not just to oil and gas, but to coal, uranium, diamonds and other minerals, any resource which is subject to depletion without replacement by natural means.

His approach brings to mind the use of pure dimensional analysis in the derivation of Reynolds number for scale effects in subsonic fluid flow,[4-6] which can also be used to derive Mach number (for supersonic flow), Froude number (for free fluid surfaces, such as for ships), Nusselt number (for heat transfer) and a host of other scaling indexes. One could enthuse and compare it with Pythagoras' proof that the square of the hypotenuse is the sum of the square of the other two sides.

Dr. Hubbert's discussion of geology and oil occurrence in nature is also elegant and eloquent. Its essence is presented here as the most lucid encountered. He points out, as do many, that oil and gas resources are much more difficult to estimate than coal or oil shale, for example, and his explanation of the physical characteristics make the reasons very clear.

In Reference 4-3, Dr. Hubbert also makes a philosophical observation which may be pondered: "A fairly widespread delusion among the citizens of the United States is that this country owes its phenomenal industrial development, as contrasted with the lack of development of regions such as Africa, South and Central America, and India, to the superiority of American personal and institutional characteristics. It may be well to remind ourselves that, but for a fortuitous combination of a large fraction of the world's resources of coal and iron in the eastern United States, the growth of which we are justly proud could never have occurred."

The example of Japan had not yet reached its impressive stature in 1962; perhaps the answer is incentive. But Hubbert makes a strong point that we should not be dissolute or complacent with our domestic energy and other resources. Also, that energy is a significant component in economic success.

Oil Geology

Paraphrasing Dr. Hubbert, if a well is drilled deep enough at any place on earth it will eventually strike some rock formed in the basic hardening of the earth's crust. This rock, called the ***basement complex***, has grains so tightly packed that the pore space is practically zero. "In many parts of the world, such as in eastern Canada, Scandinavia, and a large part of Africa, the rocks of the basement complex occur at the surface of the ground."

"In other areas these rocks are covered with a veneer of rocks such as sandstones, shales and limestones, which are sedimentary in origin. The thicknesses of these deposits of sedimentary rocks vary from zero to possibly 10 miles or more. The average thickness is probably no more than about a mile." These sediments occupy basin-like depressions in the upper surface of the basement complex. Where internal stresses have distorted and convoluted the underlying basement complex, the overlying sedimentary layers have been distorted and displaced accordingly.

These sediments were the sands and muds in which the organic remains of the geoligic past were buried and preserved, all the fossil hydrocarbons with which we are familiar. "These rocks, or contiguous fractured basement rocks, are therefore the only rocks in which commercial quantities of fossil fuels have been found or are ever expected to be found." (Methane hydrates and deep-earth methane may not fall into this classification, as discussed in Chapter 7)

Sedimentary rocks are mostly porous, with the pore volume about 20% of the total volume. This pore space forms a 3-dimensional interconnected network which is normally filled with water, having been formed in seas or lakes, or often deposited at the mouths of prehistoric rivers. "Exceptionally, in very local regions of space whose horizontal dimensions may range from from a few hundred feet to some tens of miles, oil and gas may have displaced the water in certain strata of the sedimentary deposit. These local concentrations of oil and gas in the sedimentary rocks are the sources of our commercial production of these fluids."

Hubbert notes that the initial supply is finite, the rate of renewal is negligible, and the occurrences are limited to those areas of the earth where the basement rocks are covered by thick sedimentary deposits.

"The geographical distribution of all of such basins on earth is reasonably well known. If we can estimate about how much oil and gas is contained per unit volume in the sediments in the better-known areas, such as the United States, then, by assuming comparable oil and gas contents in similar sedimentary basins in the rest of the world, an estimate in advance of extensive development can be made of the possible oil and gas that other areas may eventually produce."

"The sedimentary rocks of the United States and its continental shelves to a depth of two miles have a volume of about 3 million cubic miles. With an average porosity of 20 per cent the pore volume of these rocks would be about 600,000 cubic miles. Now suppose that these rocks contain 1,000 billion barrels of crude oil in commercially producible concentrations. The volume of this amount of oil would represent a fraction of 5.7×10^{-5} of the entire pore volume, or about 6 parts per 100,000."

"***There is no geological information in existence that will permit us to know whether this is a high figure or a low figure*** (emphasis is Hubbert's). We have no ***a priori*** way of knowing whether the average content of oil occurring in commercial quantities in sedimentary rocks should be a few parts in 100,000, or ten times or one-tenth this amount. [illegible] the only possible way we have of determining how m[illegible]h oil the United States will produce is by pure empiricism, ba[illegible]d on our actual experience in the exploration and production of petroleum."

This problem is further complicated by the nature of oil and gas. Unless trapped beneath an impermeable layer of additional

sedimentary rock, liquid material may rise to the surface, evaporate, oxidize, erode or otherwise be carried away. Gas is especially elusive. These hydrocarbons can also migrate into other porous rocks which bore no fossil material during their formation period, or into fissures in the basement rocks. As has been mentioned, the areas can be distorted by movement of the basement rock, as well as by slowly rising "bubbles" of material like salt or sulfur, which are lighter than the parent rock.

Oil Resource Analysis

In 1948, L.G. Weeks, Standard Oil of New Jersey, then the world's largest oil company, published results from a world-wide study made over several years along the general lines sketched above. Two years later at Lake Success, New York, he expanded this material for the United Nations Conference on the Conservation and Utilization of Resources. Among his comments, "As previously stated, I feel that the actual measure of oil recoverable by conventional methods and under present economies is more likely to be fifty percent larger than 10 percent smaller than my estimate of same. However, again I must warn that these are not proved reserves. The actual figure of ultimate reserves may very easily vary from my figure by considerably more than the percentages I have just cited."

Over the next few years many got into the act and estimates of both U.S. and world oil resources varied widely as individuals considered reasons why the amount should be greater or smaller. In general, however, the estimates tended to grow from Weeks' original 110 billion barrels for the U.S. to 372 billion barrels estimated by Resources for the Future. In 1958 Weeks raised his 110 billion estimate to 240 billion, including U.S. offshore. He mentioned that a means might ultimately be found to double this amount through enhanced oil recovery (EOR). The next year, Weeks raised his estimate to 460 billion barrels.

In November 1961, the U.S. Geological Survey (USGS) reported an estimate of 590 billion barrels to the Federal Science Council. The USGS bulletin remarked: "But this much is certain: it cannot be safely assumed that even the 20-percent mark has been reached in exploration for petroleum in the United States, excluding Alaska and excluding rocks deeper than 20,000 feet." With 100 billion barrels found by that time, USGS concluded that an objective estimate might soon be in sight.

Loftness notes[4-5] that USGS estimates of undiscovered U.S. oil and gas reserves increased by a factor of three from 1974 to 1975.

In his 1962 report to the National Academy, Hubbert plotted all the estimates he considered significant, as shown in Figure 4-1. He noted that, if either the highest or the lowest estimate should be right, then the others would be hopelessly out of range.

"If the correct figure happened to fall about mid-range, say at 370 billion barrels, then the errors on either side would range between zero and about 200 billion barrels. It is thus demonstrable . . . that the preponderance of recent attempts to determine this quantity are grossly in error. This raises the question of whether the desired quantity is intrinsically indeterminate, except within these wide limits, or whether from data now available it should be possible to determine this quantity within a much narrower range of uncertainty. It is the thesis of the present report that such data do exist, and that from them a much more reliable estimate can be made."

Hubbert's Analysis

"The method we shall now employ makes explicit use only of the two most reliable series of statistics of the petroleum industry: (1) the quantity of crude oil produced in the United States per year, for which data are available annually since 1860, and (2) the estimates of proved reserves of crude oil in the United States made annually since 1937 by the Committee on Petroleum Reserves of the American Petroleum Institute."

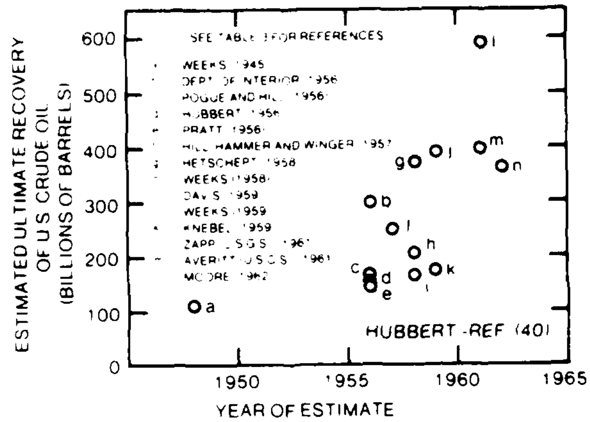

Figure 4-1
Estimates of Ultimate Recovery of Crude Oil

(Critics are uncomfortable with the data from API, being subject to reporting policies of the individual oil companies. But there is no better source; each oil company is likewise dependent on the reporting integrity of its peers).

Hubbert then listed a series of definitions and notations, which will not be used here. His mathematics will also be skipped and the highlights described verbally.

He discusses the basis for statistical analysis, particularly the way in which U.S. oil production has accumulated with time since 1860. The resulting curve is shown in Fig. 4-2 of this document. It is accompanied by a similar curve of cumulated proved discoveries, also shown in Fig. 4-2. The curves of cumulative discovery and cumulative production turned out to be identical, but displaced by a constant spread of years. Hubbert observes that a time plot of proved reserves (the only source from which oil can actually be produced) starts at zero and rises to a maximum at about the halfway point, and then gradually declines to zero, also shown in Fig. 4-2.

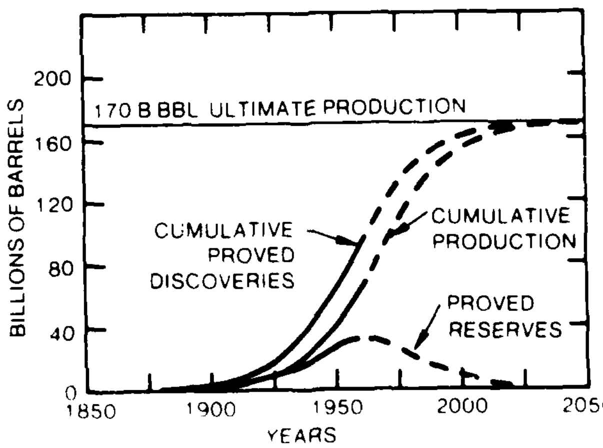

Figure 4-2
Hubbert's 1962 Oil Depletion Analysis

If U.S. oil production follows this trend uninterrupted to completion, the final oil would be produced in about year 2030. Also, using the statistical formula which is derived from curve-matching both cumulated discoveries and production, the total oil produced in the U.S. should be close to 170 billion barrels, much lower than many of the previous estimates.

Hubbert has been criticized unjustly in that most of his curves discussed elsewhere, as these, are symmetrical about the midpoint. Hubbert's papers discuss the fact that there is no reason to assume symmetry; he points out the fact that the time plot of proved reserves can have a variety of shapes, with double or multiple maxima. The reason his curves take the shape they do is that they have been constructed to match the data. Then, from having matched the data, he deduces the characteristics of the phenomena from the shapes of the curves.

By the same token, however, curves that matched the data in the past will not necessarily forecast future events, if the forces affecting future events are significantly different from those which guided the past. Hubbert also fully acknowledges that principle.

But, using the data available in 1962, the results were not only consistent and elegant at that time, they have been borne out by subsequent experience, at least until 1980.

The solid lines in Fig. 4-2 are from data available to Hubbert at that time; the dotted portion of the lines are extrapolated using the formulas derived from the actual data. Data for cumulative production are so consistent that they plot, literally, within the width of the line shown in Fig. 4-2. As would be expected, discoveries are not quite so consistent; they vary by effort and luck from year to year. But over the 200-year base of Fig. 4-2, the cumulative discoveries wandered little more than three times the width of the line. That means no more than a width of the line from the line as shown, at this scale. The consistency is remarkable.

Data scatter (which is not shown by Fig. 4-2) simply makes the discovery line appear to be more freehand than mechanical, but the trend is consistent and true. From the two curves, Hubbert could deduce accurately that production lags discovery by 10.5 years. That is, after new oil is discovered, historically it has taken an average of 10.5 years to produce it.

Moving from the cumulative data, he then examined the rate data more closely. On an enlarged scale, Figure 4-3 shows the actual data for rate of production from 1875 through 1962 and, simplified, indicates the corresponding curve for rate of discovery. The 10.5-year lag is confirmed. Since a rate is mathematically a first derivative (the slope of the cumulative curve at any point in time), rates or slopes would be expected to show more irregularity than the cumulative data. So the variation of Fig. 4-3 is not at all surprising. What is surprising is that it is still so consistent.

As shown in Fig. 4-3, Hubbert indicated that the real test of what was happening and when it would happen, must be represented by the second derivative: the rate of change in reserves. Again, mathematically, since the second derivative is the slope of the first derivative, a plot of that function would be expected to be substantially more erratic. The data available to Hubbert in 1962 are shown in Figure 4-4. Being a function of discoveries (change in reserves is the difference between oil produced and oil discovered in any given year), this curve would be expected to show considerable irregularity from year to year. It is the general trend which is important.

The date at which the change of proved reserves reaches zero therefore assumes primary importance, at least from a conceptual standpoint. For, when the theoretical curve of Fig. 4-4 crosses the axis from positive to negative, the rate of production

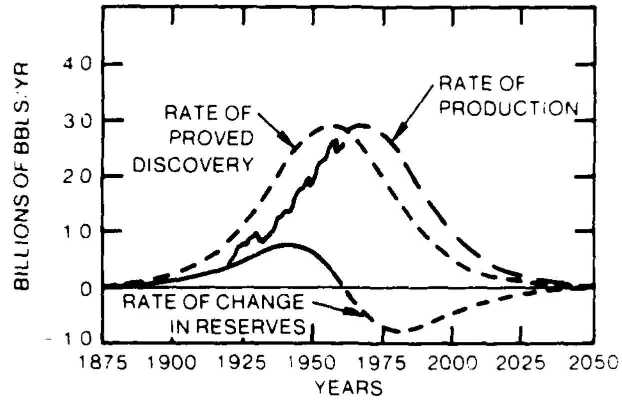

Figure 4-3
Correlation of Hubbert Analysis

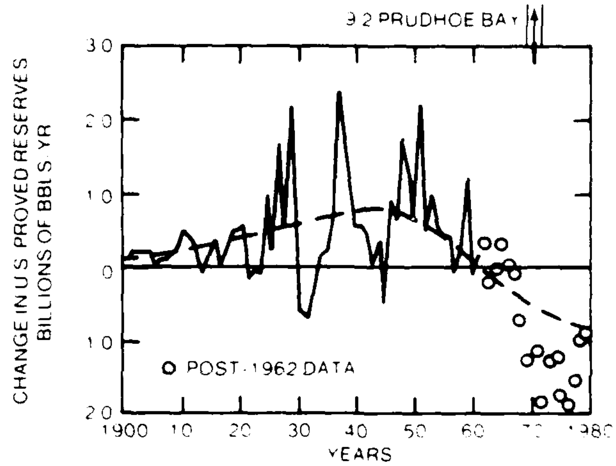

Figure 4-4

must have peaked. Except for year-to-year variations and luck, once the change of proved reserves truly crosses to the negative side, production must inevitably decline out toward final exhaustion!

Of course, production could be accelerated artificially, and even finding rates could be given a temporary boost by artificially increasing exploration. But if the success of the past has been primarily the result of the earth's geology and if oil exploration and production have been shaped by events inherent in world history, the curves should play out as shown. Any near-term acceleration in production would simply create a balancing acceleration in decline sometime later.

Figure 4-4 deserves further attention. Variations in the data represent the way oil has been found in the United States since 1900. As Hubbert and others point out, the variations have been largely due to changes in geological knowledge, wars and variations in economic activity, including the depression of the 1930s. In these data, oil historians can point out all the individual fields and finds; they should, that's where the data come from!

In 1962, Hubbert could see that proved reserves should have crossed from positive to negative early in 1961. Applying his 10.5 year spread then, the data indicated that the peak of U.S. production might occur in 1970, or a little beyond. Historically,

that is what has happened: U.S. oil production was greater in 1970 than in any year before or since!

This author has added plotted data to Fig. 4-4 from 1963 through 1980, as reported by the DOE. They show that the discovery of Prudhoe Bay, Alaska in 1970 is completely off the scale. Some critics have made much of that point. But Prudhoe Bay is still only a single point on a trend line. Looking at the other points over many years, it is clearly an anomaly. Nothing approaching Prudhoe Bay has been reported in the U.S. before; ***we cannot expect to find Prudhoe Bays very often***, if ever again. Looking at points over the other years, the variation is still there, and the trend for proved reserves is unquestionably from positive to negative at around 1961-63.

Although the data points from 1961 to 1967 are a little more encouraging, the data from 1968 to the present, except for Prudhoe Bay, ***are all firmly negative***. Any mathematical analysis, any eyeball analysis, would have to conclude that Hubbert's forecasts not only look as good now as when he proposed them, but that his predictions have come to pass with remarkable accuracy. The whole concept, the methods and results, are all extremely impressive.

(It must also be noted, however, that domestic drilling dropped off rapidly toward the end of the 1960s when oil was found and produced so much cheaper in the Middle East. It is only in the 1970s, and generally since oil deregulation, that domestic activity has resumed.)

While the process will not be reviewed here, Hubbert also checked his conclusions independently by analyzing results separately from large fields and small fields, giant fields being those expected to produce more than 100 million barrels. The Rand Corporation and others have also run analyses of this type. Answers correlate well. The consensus is that, as long as one uses the same basic recorded data, no matter how one approaches the subject and what his method of analysis, he should get essentially the same results as Hubbert.

At least we no longer have contention among the physical analysts, as we did before Hubbert's reports. Now we have those who accept the statistics for forecasting, versus those who believe that physical data are not significant in forecasting future petroleum production.

The questions and the conditions that critics have raised were largely anticipated by Hubbert. He does not contend that the future is inexorably bound to the past or that future conditions could not change or reverse experience up to date. He simply points out that this is what the data tell us so far. The same trends have been seen for other minerals and, in fact, with other types of variables which depend on similar depletion or production characteristics.

Hubbert and his supporters ask whether new prices, new land openings, relief from taxes and regulations, new technology (which also occurred throughout the recorded period), indeed whether anything new in the world, can affect the picture as projected. After all, hundreds of thousands of wells and hundreds of billions of barrels of oil produced (100 billion from U.S. wells) should tell us something about the ground rules. Can the ground rules have changed enough to affect the outcome?

Economists are not wedded to history or technology. To the above questions, they answer, "Yes." And they move on accordingly.

Oil Production Forecasting by Economics

The author has seen no formal economic argument which refutes Hubbert's physical forecast of crude oil production. The economist sees no need to engage in debate. Hubbert himself pointed out many variables which, if changed in the future, would lead to different conclusions. The economist simply accepts it as apparent that these changes have now taken place. The most obvious may be the rise of crude oil prices, shown in Figure 1-1, which is repeated here as Figure 4-5 for convenience and emphasis.

If most of the history of petroleum production took place in a world of two-dollar oil and only the last few years are exceptions, the economist would say that the hundreds of thousands of wells and the hundreds of billions of barrels were recorded in a different world than today. All the ramifications are apparent to him and require no elaboration. Many of these factors and consequences have been noted before, sprinkled through the report.

They include the withholding of federal land from production and even from exploration. Geologists agree that offshore lands probably hold more reserves than onshore, while we've just begun on that prospect. Drillers are finding layers of oil folded into more complex geological formations and, equally important, ways have been developed for locating these fields. Hubbert's original assessment ended at 10,000 ft. depth. His limit has since been extended, but oil is being found at depths previously thought unrealistic. Some believe that even vaster amounts may be found in deeper offshore water. (But can production be economical?)

By simple economics, some operations such as the Belleview Field in North Louisiana, stopped pumping in the 1920s after only 5% of the known oil in place was extracted. The remaining oil was too thick to pay for costs of pumps and fuel. With the price rises of Fig. 4-5, it is all too apparent how new pumps can

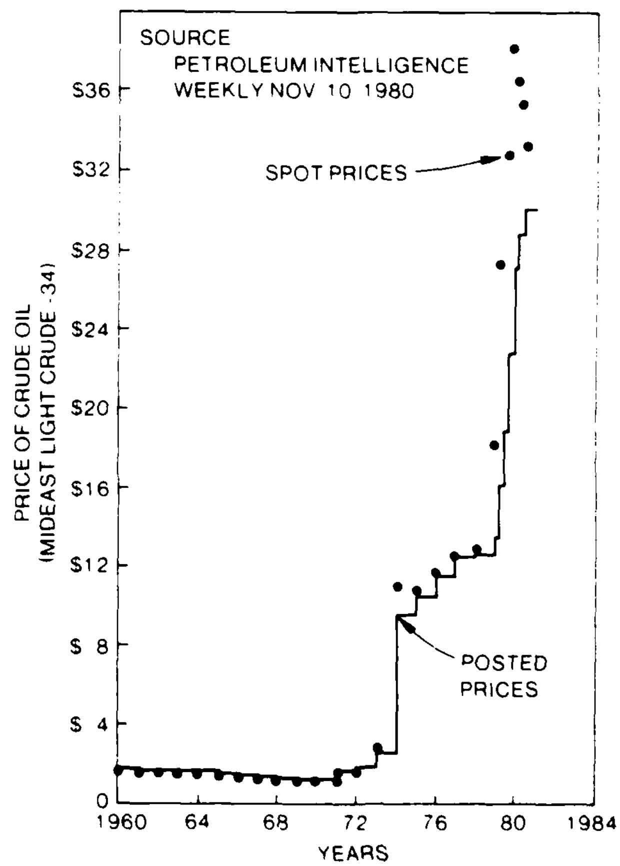

Figure 4-5

be bought and operated, how steam can be injected to reduce the oil's viscosity, how chemical extraction might become feasible, and how agents such as carbon dioxide can be pipelined to wells and injected to stimulate new production. With only about a third of the known oil produced from all the fields in the U.S. and the world, even after water flooding, economics can dramatically increase reserves as well as production prospects. And that can occur without any further exploration or drilling.

One further, final example will be given simply to illustrate the case for the economists. There are many other examples, but it may not even matter what the total U.S. resources might be. As mentioned previously, unless new finds can be produced below the current marginal market price of crude oil, or unless so much oil can be produced at the marginal price that the world price is held down, it really doesn't matter if the oil is there or not. At least, it will not participate in the market until the marginal price rises enough to make production economically attractive.

That is the point of the economists: supply will be produced to meet demand as long as the user will pay the price.

Back to the final example. Seismic exploration and exploratory drilling for oil are expensive. Exploration depends on demand. As fuel is the largest cost component of airline direct operating costs (DOC), exploratory drilling is the largest cost component in the entire oil production process. Money is returned on that investment only when the oil found is produced and sold.

Unless the market is demanding oil at a price which makes exploration and production profitable, then money should not be spent to prove reserves earlier than they will be produced. This is particularly true in a time of high interest rates. Further, taxes are applied to known oil reserves. So knowledge on reserves will never be complete, consistent from various producers, or necessarily reported before they are planned to be produced.

Proved oil reserves may be a liability, rather than an asset to the owner, except for raising capital, for promotion, and the like. Ideally from the economic point of view, we should have no reserves. We should not spend money to establish an unused inventory. Indeed, the history of oil "discoveries" indicates very strongly that oil finds are not necessarily reported when encountered; they are reported at the convenience of the owner. Much of the wide data variation in Fig. 4-4 may be due to economics and taxes, rather than to geology and finding success.

H. William Menard, Director of the USGS notes[4-7] the effect of taxes on oil finds: "Restraint in exploratory drilling is encouraged by the common practice of levying property taxes on the volume of declared oil reserves. A notable example is the restraint exercised by industry in drilling the almost continuous oil sands of the giant Dominguez oil field in California. Following the discovery of oil at the '1st Callender' horizon at a depth of 3,950 feet in 1923, it was 13 years before the drilling was extended a further 3,000 feet. In that period additional oil was 'discovered' at seven lower horizons."

Taxes may exert a stronger restraint on oil discoveries than technology can provide incentives. This is absolutely proved in enhanced oil recovery, where many fields are currently not being produced because of adverse tax structure. The difference with EOR is that the oil was known positively to exist before production was stopped. Oil never produced may remain "unknown," unrecorded, and therefore nonexistent in the data used for statistical and other analyses. A favorable change in price, regulations or taxes can instantaneously spring such oil into activity!

The economist need not concern himself with these matters. He is confident the oil will be produced when market conditions make production attractive. Therefore, he applies his attention to market conditions. As would be expected, this view is generally more concerned with the shorter spans of time. After all, who knows what the world's economic or political conditions may be in ten years, five years, or even next month? Certainly no one engaged in economics will concern himself about proved oil reserves out to 2000 or 2050. Reserves proved that far in advance of market requirements are by definition an economic heresy!

Pragmatic Oil Production

As pointed out by speakers at the Houston conference, oil companies generally approach forecasting and production from the standpoint of annual market demand. From their forecast of the market, they plan their refinery output schedules for each type of product. These demands will then be met by reviewing their oil-well and land-leasing schedules, adjusting their exploratory activity accordingly.

Very sensitive economic analyses of costs, regulations and taxes determine where their investments will be made, starting with major geologic areas and working down to specific locations and individual wells. These projected costs and investments must be balanced off against refinery, shipping, distribution, and other costs and considerations, including prices, grades and locations of crude stocks which may be bought on the market. Decisions are made by working the list of properties down from the most economically attractive as far as necessary to meet the market forecast. Obviously, if some properties look unattractive from the standpoint of costs, taxes, etc., their production will be deferred, they may be traded, or their options may be allowed to expire. What is productive for one company and its set of conditions may not be economic for another organization at the same time.

Market demand forecasts beyond a couple of years are considered fuzzy because of the recent unprecedented market fluctuations. Long-range supply forecasts are still based largely on proven technology, but economics is what drives the rate of production.

This process is even more fundamental with producers like Occidental, which have no refineries and, particularly, no retail outlets. With them, there are no compromises to serve particular customers or to support refinery peculiarities. A barrel of oil may have peculiarities of its own, but its market is active. Out there somewhere is a customer who will buy it at its going market price. So the decisions on production and associated activities are very direct for these organizations. Curiously, the same staff officer at Occidental who outlined these pragmatic operations, also suggested that The Institute for the Future might provide valuable inputs for this study. Even pragmatism, apparently, is guided by long-range planning.

The flavor of the Houston meeting can be caught from brief remarks by some of the speakers:

Charles L. Campbell, Senior Vice President, Gulf Trading and Transportation Company: "It is easy to place all the blame for our energy problems on OPEC, but the fact is that we are responsible. OPEC is only acting in their self interest. The U.S. possesses the world's most abundant supply of untapped energy sources — crude oil, natural gas, coal, oil shale and uranium. But we are doing amazingly little to develop these resources properly."

"... If we in the energy industry are going to help the nation make a successful transition to the era of synthetic and

renewable energy resources — if we are going to become less dependent on unreliable imported oil — we must be able to rely on government to do what it promises to do. We must know that government will not retroactively interpret the rules and regulations. We must be assured that the government will not impose punitive and discriminatory taxes and restrictions. . . . On the other hand, government has an equal right to expect those of us in the energy industry to keep our word, to act responsibly and to present the facts fairly and honestly. . . . This kind of trust is a fragile, intangible, almost delicate thing. Once it is lost, it is terribly difficult to rebuild."

Robert W. Witt, Jr., Consultant, Market Analysis Group, The Pace Company Consultants and Engineers: "Offshore crude oil production is projected to increase from 13 percent of total Western Hemisphere production in 1980 to over 22 percent by 1990. Mexico is projected to have the largest increase in offshore crude oil production, up from 90,000 barrels per day in 1979 to 2.5 million barrels per day by 1990."

". . . In the North American offshore acreage, 74 percent of the total continental shelf is considered geologically prospective. As of May 1980, only 19 percent of the geologically prospective acreage was under some form of lease/license arrangement. However, *less than one-half of one percent of the* Alaskan acreage — having some of the highest hydrocarbon potential of any region in the Western Hemisphere — is under state and/or federal lease. . . . It is important to note that the number of exploratory and development wells drilled from 1975 to 1979 in the Gulf of Mexico has not increased in line with what mobile rig demand would suggest. The factors which are influencing mobile rig demand in the Gulf include the United States leasing policy, and the average size field being discovered and developed has been decreasing."

Dr. Eva Norrblom, Special Assistant to the Director of Federal Agencies, American Petroleum Institute: "Forecasts made in recent years by consultants, government and industry are projecting significantly lower levels of production in 1985 and 1990 than estimates made five and six years ago. The more recent projections of U.S. crude oil and natural gas liquids production in the 1990s are more than 35 percent lower than earlier estimates. . . . In summary, the increased pessimism about the outlook for U.S. domestic oil production is due primarily to U.S. government policies. . . . The greatest uncertainty shows up in the estimates for future discoveries in Alaska and the Lower 48 states. For production from EOR techniques, the projections differ depending on the assumptions made about oil prices, WPT (windfall profit tax) and recovery costs, including costs of environmental restrictions."

"Exploration on government-owned lands must be accelerated to allow the size of potential areas to be determined. This information is vital since estimates of domestic production may have a significant impact on U.S. policy decisions to adopt strategies that promote inter-fuel substitution, reduce demand and speed up the commercialization of alternatives to oil."

Frederick Z. Mills, Vice President, Rotan Mosle: "In our previous report, 'The Outlook for Domestic Drilling,' dated May 1, 1980, we examined the historical drilling response to changes in real price of oil. Applying this relationship to recent changes in oil prices, we projected a boom in oil field activity lasting well into the 1980s. In this new report (March 1981), we analyze how historical drilling activity and expenditures have related to the primary source of funds for drilling, i.e., revenues realized from the production of oil and gas. . . . The analysis is based on oil and gas policies in effect at this time."

"Our principal assumption in this analysis is that the market price of oil will grow at an average rate of 13 percent, reaching $77 per barrel by mid-1986 . . . Production of oil will reach ten million B/D by 1986." (note in Fig. 4-3 that Hubbert's curve would indicate about 7 million barrels per day production at that time — 2.5 billion/year divided by 365 days.)

John M. Iannone, Vice President, Oil Department, H. Zinder & Associates: "Thus, price controls and federal land restrictions and environmental delays have given a distorted picture of the U.S. petroleum resource base. The terrible irony of all this is that the U.S. is one of the few oil importing nations that could be using its own oil resources to help stabilize — or perhaps even cut — oil imports over the next several years. . . . it's reasonable to hope that the U.S. could, with current incentives and future prices, maintain oil and natural gas liquids production toward the higher end of the ranges I discussed earlier — around 10 million barrels a day. It's reasonable to expect that the U.S. could stabilize oil production at something close to present levels and hold that for more than a decade, as many of the forecasts say."

". . . a similar line of reasoning and conclusion holds for other important U.S. fuels — coal and nuclear energy now, and *the prospects for significant synthetic fuel supplies in the future.* . . . I believe that this evidence and discussion illustrates the the U.S. energy problem is not a resource problem but a political problem . . ."

The Georgetown CSIS Forum

At the Georgetown Center for Strategic and International Studies[1-2] on October 20, 1981, the subject of oil production outlook was discussed by Dr. Theodore R. Eck, Chief Economist, Standard Oil Company of Indiana (Amoco) and by Oswald W. Girard, Jr., Deputy Chief for Oil and Gas Resources, U.S. Geological Survey. Following them, Dr. Joseph D. Parent, Consultant and Dean Emeritus of the Institute of Gas Technology, commented from his viewpoint of long having analyzed and compared the energy resource forecasts available in the Free World. Their views are best expressed in some of their own words.

At a previous meeting in Washington,[4-1] Dr. Eck was introduced as representing the company which has spent the most money in exploration, drilled the most wells, and found the most oil in the world. The essence of his message was, "We think there is an immense amount of material still to be found in the U.S., OPEC and especially in the Free World. When you see what's happening with exploration activity, there's a tremendous increase in activity outside of OPEC overseas."

"We're starting to get some major discoveries, some of which have and some of which have not been announced. We're developing some new major discoveries, much of which is gas. We continue to discover more hydrocarbons overseas than we're producing and the production line is flattening out. We think in the future that discoveries will exceed or at least match production, so there is no indication of a supply restraint for geologic reasons."

"Our forecast shows the world oil production increasing steadily out through the end of this century. We do not concur with the forecasts that expect world oil production to peak in the 1990s. We view the peak as well after 2000."

"That isn't meant to say that the world will be swimming in oil; this is excess in the sense that it isn't going to be produced. But the capability of increasing production exists and will represent some sort of discipline on world oil prices. That's particularly true in that more than half of that surplus is in Saudi Arabia

and they have the capacity to maintain that share into effective infinity, due to their immense resource base."

"To finish up my optimistic viewpoint of where the U.S. petroleum business is going: This is a great year; we're going to drill 77,000 wells, more than twice as many wells as we drilled four years ago. . . . Last year was a great year. We think we found as much in this country as we produced and you will notice that oil production is headed up, rather than down."

"As economists, I think we are guilty of underestimating the elasticity of both supply and demand. The world oil picture may balance even more quickly than we suggest." His comments already have been borne out in demand; the supply-side reports are yet to come in.

Mr. Girard acknowledged the amount of exploration going on, but remarked that he could not share the enthusiasm in domestic or world prospects. As opposed to drilling rate, he notes that finding rate, ". . . especially in the U.S., is a dramatically declining curve." He agrees that the percentage of dry wells has declined, ". . . and that a lot of new wells and fields are coming in. But the supply is not really coming in to turn up the curve. In fact, the USGS just completed a study of all the offshore areas of the world, excluding the Soviet Union and China, and the same type of decline curve is apparent in all the offshore areas as in the Lower 48. To me, the evidence is overwhelming that the supply really is not there."

"There is another problem. In order to meet consumption, you need to deliver the product at a particular rate. I think this country is well endowed with resources and the resources are there world-wide. However, the field-size distribution of these resources, as well as for shale oil, geopressured zone, oil and gas from eastern shale, does not allow them to be put on line and produced at the rate we need. It's like draining an Olympic-sized swimming pool with a garden hose." (Also see Reference 4-7 on this point.)

"If you believe our numbers, we've already discovered between 60-75% of all our conventional gas and only discovered between 55-66% of all our conventional oil. I don't like looking at rates, but at current consumption: our oil will last 11-18 years and the gas 24-37 years. That just gives a feel for the size of the numbers. It is a dangerous guessing game."

Dr. Parent remarked that he basically uses USGS data, evaluating it along with everything he sees published in the U.S. "The trend of oil and gas discoveries in Mexico has been interesting to me. Mexico produced oil before 1900 and was the second-biggest producer in the world in 1920. Forecasters may note that when the well logs were re-examined from the Reforma Field and deeper drills were made, they came into hugh amounts of new oil and gas. These would never have been forecast on the basis of the finds at shallower depths. . . . In the early history of a process, you can probably fit any number of equations to the data and extrapolate them to almost any value you want."

Tapes from the Georgetown CSIS meeting are included in Appendix C.

So there we have it. Are we in the declining phase of a long-drained resource, or are we on the threshold of new finds in new provinces and at greater horizon depths? It is too early yet to tell with certainty. If the situation should actually be favorable, 1981 and 1982 drilling results should give some indication. On the other hand, it may take until 1983 to establish any real validity.

But with our demand down and likely to continue downward, the outcome now may carry less pressure. Our world demand is now below world production capacity and it is no longer strictly a seller's market. Let's hope it will stay that way for a while.

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Chapter 5

Enhanced Oil Recovery (EOR)

Board Room Briefing No. 5

1. On the average, in both the United States and the world, only about 1/3 of the original oil in existing reservoirs is produced by primary (natural pressure and pumping) and secondary (waterflooding) methods. With today's technology, the potential exists to produce an additional 10-15% of the original oil in place from existing wells by tertiary or enhanced oil recovery (EOR).

2. The consequences of the above conclusion mean that oil recovered from the average of all existing fields in the world, including abandoned fields, and all the new fields yet to be discovered, could be increased by 30-50% through EOR. If brought to reality, the results would have almost inconceivable effects on the world energy situation. If achieved in the United States alone, it could greatly reduce or eventually eliminate our need to import foreign oil, with all the military, political and economic ramifications associated with that dependence.

3. In the U.S. today, EOR contributes only about 3% of the national domestic production; its near-term potential could be at least 10-15%. Since EOR should continue and enhance future petroleum finds, EOR production should increase further with time, at least through year 2000. Encouragement of EOR production would appear to be one of the most immediate, certain and effective avenues the U.S. might use to improve its energy situation before synthetic fuels become available in appreciable quantities.

4. With some exceptions, EOR is very risky and technically difficult, but techniques have been developed for many ways of proceeding. EOR is generally less risky and less expensive in recovering heavy oils by thermally-assisted methods.

5. EOR is expensive. In addition to the initial drilling costs, secondary production costs another about 5 cents per barrel. By comparison, tertiary or EOR incremental production costs average about $15 per barrel.

6. Federal regulations and taxes are the most restrictive forces inhibiting EOR production in the U.S. Even with technological advances and tremendous increases in crude oil prices, EOR remains at about the same production rate today as it did ten years ago. Unless U.S. taxes and regulations are revised to encourage EOR, it is likely to remain a small contributor to U.S. energy production.

7. Thermal extraction accounts for three-quarters of U.S. EOR and its percentage of EOR production is on the increase. Thermal methods are usually used for heavy oil; heavy oil is by no means such a high percentage of U.S. oil resources. Thermal extraction is usually limited to shallow fields, where both risks and costs are relatively low. Only such favorable conditions can overcome the unfavorable institutional restrictions on EOR production.

8. EOR by other, chemical methods has reached a high degree of sophistication, but considerable testing, analysis, preparation, investment, time and risk are involved before production can begin at any given location. With these natural hazards likely to remain in force, the only possibility for significant expansion of EOR appears to be by reducing its institutional barriers.

Why EOR?

"Why is oil difficult to extract? The basic reason is that oil does not exist in underground pools as commonly thought. Instead, it clings to the microscopic pores of sandstone. Hold a typical oil-bearing rock in your hand and without a microscope, you would have difficulty telling that it was anything but rock . . . After as little as 10 percent of the oil is extracted, the production is so slow that the well becomes 'dry.' Primary production is over. To extract more oil, enhanced oil recovery methods are required."

"Enhanced oil recovery (EOR) is simply the injection of a fluid which speeds the flow of oil toward the producing well and also sweeps more oil out of the porous rock. The speed at which the oil can be driven through the reservoir depends on the permeability of the rock and the viscosity (or thickness) of the oil, and the driving mechanism."(5.1)

Permeability is a measure of how well the rock pores are interconnected. Although oil-bearing rocks are as dense as a brick or a concrete floor, the pores are connected by passages. This permeability has been compared to the hallway network in a building, where the rooms are likened to the rock pores. The hallways have their own characteristics, almost independent of the rooms. This becomes evident in a building during a fire drill. Depending on their average widths, constrictions, multiple paths, twists and turns, etc., the interconnections between pores may affect oil recovery as much as the characteristics of pores themselves.

"The simplest technique for enhancing oil recovery is water flooding. A new borehole is drilled in the vicinity of one or more producing wells and water is pumped into the the oil producing formations at selected intervals depending on the geology. As the water moves into the rock, it provides the necessary pressure to keep the oil flowing toward the producing well. The exact location of the well and the selection of water injection points requires considerable geologic expertise."

"The technique, which has been practiced since the 1920s, is the recovery method that is usually first employed after pumping no longer produces oil at a reasonable rate. Today waterflooding is used as secondary recovery in 90 percent of the U.S. oil fields."(5.1)

By definition in the oil industry, the term Enhanced Oil Recovery (EOR) is now generally reserved for tertiary recovery from an oil well or field. Primary recovery is by natural pressure or pumping. Waterflooding is now usually called secondary recovery. Tertiary recovery is use of steam, heat (such as by fireflooding, or underground combustion), gas, or fluids other than plain water. Today, EOR usually refers only to tertiary recovery and does not include waterflooding. So literature may be somewhat ambiguous, depending on its age.

There are apparently rare cases when production of a well or field goes directly from primary to teriary methods, skipping the waterflooding stage. But waterflooding is not only common, it is practically the rule. Approximately half of the oil being produced in the United States today is by primary production. Virtually all of the remaining oil produced, the other half, is by secondary production, waterflooding. The necessary conclusion is that an almost negligible contribution is being made now by tertiary production.

EOR has received a fair amount of attention in both the press and the oil industry, as well as considerable and intensive research effort. It is a large undertaking in some fields and may draw active interest. Today, EOR accounts for between 250,000 and 400,000 b/d of the oil produced in the U.S., which is enough to feed two or three respectable refineries. But, considering that the U.S. produced over ten million b/d in 1981, EOR accounts for only about 3%. If EOR could be converted 100% into jet fuel, it would supply only one-quarter of demand in the U.S. The amount may appear hardly worth discussing.

But in the U.S. and around the world, on average only about one-third of the oil known to exist in fields is produced by both primary and secondary means together before the fields are shut down. The other two-thirds of the oil which remains there unproduced is fully located and identified. There is no question about its being there. Production problems, taxes, regulations, economic conditions, risks, or alternative, more attractive investment options, have convinced the producer that recovering that oil is not economically attractive.

It might be thought that U.S. oil production technology being the most advanced, we should be producing a higher percentage of our oil than wells abroad. Ironically, most of the foreign fields operate on U.S. technology, while OPEC countries, for example, not only have been developed with later U.S. technology, they have funds more readily accessible for production investment.

So U.S. EOR production percentage runs about even with the world average. Oil price decontrol in the U.S. might be expected to stimulate EOR here in the future and to soon increase our percentage of oil recovered from domestic fields. But, as will be discussed later, regulations and taxes are still not favorable to EOR. Most operators find that wildcatting is a more attractive economic venture than EOR.

As was mentioned earlier, the Bellevue field in Louisiana was originally developed during the 1920s, but only 5% of the oil known to exist in the field was extracted before operations were shut down. The viscosity of its oil was so high that pumping costs became uneconomic. In one heavy oil field in California, steam increased the production from 1% to 38% of the original oil in place.

Oil price rises (Fig. 4-5) have improved that picture, but the taxes levied on old oil are more stringent than those on new discoveries. EOR still holds a frustrating potential which has not been realized. It is a known quantity, here and now. It could reduce our dependence on foreign imports. If exploited, it would help our national energy picture much in this decade, before alternative energy resources can be developed. Economically, it could help us bridge the transition period, putting the pressure on OPEC and world oil prices.

With advanced EOR development, OPEC resources in the ground and all the other oil stocks in the world are automatically raised. If we can improve that 33% recovery to 35%, 40% or 50%, we are increasing the world's stock available by the same factor, improving the supply/demand balance, increasing the production capacity, decreasing the decline rate, and all those good things that mean more oil at lower prices for more years.

Better EOR would also decrease mental tension in OPEC and other less developed oil-producing countries, because it would offer them more time to develop their economies before their oil runs out. In a market where psychology can have such an impact, EOR could be a major factor. We have certainly seen the panic effect a shortage has had on oil prices; one would hope that increased confidence in the supply would have the opposite effect.

EOR Potential

The U.S. DOE Bartlesville Energy Technology Center (BETC) is responsible for the Government's contract activity in EOR. (Bartlesville, Oklahoma is also the home of Phillips Petroleum). As expressed by Harry R. Johnson, Director of BETC, (5.2) "The domestic target for EOR is enormous. A total of 450 billion barrels of oil have been discovered — this is not speculation but demonstrable fact."

"Of this total, only 118 billion barrels have been produced so far (nearer 140 billion barrels, now in early 1982) — that is roughly one-quarter of the total. Best estimates indicate that 28 billion barrels of reserves remain to be produced by primary and secondary methods."

"Through the application of current and advanced enhanced recovery techniques we believe that an ***additional*** 18 to 52 billion barrels can be recovered. This amount of oil is equal to the total output of about 70 synfuel plants, each producing 100,000 BPD over a 20 year period. . . . Still, over 250 billion barrels would remain as a target for future generations of Americans, using techniques which are only concepts today."

(Note that Johnson's estimate of 450 billion barrels does not correspond to Hubbert's 170 billion barrels of U.S. resources because Hubbert's method projects recovery only in proportion with past experience. Johnson's 140 billion barrels produced compare closer to Hubbert, where Hubbert concluded the U.S. was half-way through its production cycle in 1970. Or, looking at it the other way, Hubbert would be saying that about one-third of Johnson's oil resource would be produced by the conventional, historical methods; so the two are in reasonable agreement.)

Although a potential of from 18 to 52 billion barrels from EOR may appear small, the lower figure is ". . . greater than all the oil expected to be recovered from the Prudhoe Bay and Gulf Coast combined."(5.4) And, "When all of these sources are considered, the ***potential target*** is 55 billion barrels — 35 billion barrels in sandstone reservoirs and 20 billion barrels in

carbonated. Combined with conventional production, the ultimate recovery efficiency overall would be about 45 percent — a good target to shoot for."[5.4]

Further, if new oil discoveries are made beyond the Hubbert or probabilistic forecasts, a recovery factor of 45-50% instead of 33-35% could be applied, which means more oil all around.

And there is the economic potential. June 28-29, 1979, the DOE held a symposium on EOR technology at Williamsburg, Virginia. At the opening of the meeting, Richard Hertzberg, then Director, Division of Fossil Fuel Extraction, DOE, remarked,[5.5] "After the sessions, when you walk down through the restoration and to the House of Burgesses, you might realize that our situation has not changed much. When the founders of the nation debated the great events of the 1700s in the House of Burgesses, they were true revolutionaries. They were reacting to the unfair tax structure of the crown and the fact that they did not control their own destiny."

"This morning I listened to the ***Today Show*** and heard that OPEC is talking about a $23.50 ceiling price, with the Saudis holding out for about $18.00. In terms of our imports that is approximately $200 million a day that we are now paying for oil imports. With these outlays and the uncertainty of imports, it is questionable whether we are in fact in control of our own destiny. What will our response be? Mr. Fumich mentioned that there is a major debate underway on the Hill. Synthetic fuels are the primary topic of discussion; although EOR is also being mentioned, every major technology is being examined as to its potential for contributing to domestic production."

EOR started with the Bureau of Mines and was expanded by ERDA, whose goal was to produce 900,000 barrels a day. ERDA has come and gone; the DOE is either on its way out or severely curtailed. In EOR, we are producing only about a third of the ERDA goal, nowhere near the 900,000 b/d believed economically and technically possible several years ago, ***before the 1979-80 major jump in oil prices!***

Oh, for the good old days of 1979, when the price of oil was being debated around $20 a barrel, only ten times the historic price, when we paid only $200 million a day for oil imports, and when we thought our "House of Burgesses" was going to loose the might of America against its fuel problems!

EOR Methods

The mechanisms used for EOR include: (1) steam injection, to reduce viscosity of the oil, scrub it from the rock pores, and drive it toward the producing well; (2) fire-flooding (underground combustion) to provide heat and reduce viscosity; (3) miscible fluids or gases, with which oil is soluble, and which can therefore release oil from its pores and transport it toward the well; (4) chemicals or detergents, which act about the same as solvents; (5) micellar solutions, which fill up open channels in the rock pores, so as to force the scavenging fluid through the volume of rock otherwise bypassed or short-circuited; and (6) mining the rock, somewhat like oil shale. These will be reviewed briefly and the outlook for all will be discussed jointly.

Steam Drive

At the DOE Williamsburg conference, heavy oil was discussed by Dr. Todd M. Doscher, Pahlavi Professor of Petroleum Engineering, University of Southern California.[5.6] (The name "Pahlavi" is nostalgic, the surname of the Shah of Iran). Professor Doscher had been with Shell Oil during WW II and in 1957, when Egypt sank 40 ships in the Suez Canal and cut off its flow of tankers. Shell then intensified its interest in heavy oil in Venezuela, Alberta and Yorba Linda, California.

Dr. Doscher remarked, "Heavy oil is oil that is so viscous that traditional primary and secondary operations result in a very small, a few percent or less, recovery of the resource. These accumulations were known because they were shallow and had seeped to the surface. In addition, they often gave us indication of the location of lighter oils at greater depths."

"Two technologies were investigated — the use of solvent and the use of heat. The former was abandoned rather quickly. Heat, on the other hand, appeared to have promise. In the laboratory, it was relatively easy to fill a tube with greasy sand, put steam through it, and recover all the oil."

"One day we received a telegram from Venezuela stating that the well in which the steam was being injected had blown out around the casing. . . . The well was recompleted; the test was continued; but the well blew out again a short time later."

"This time it was too difficult to plug the well. The hole around the wellbore was too big. However, it was observed that after the steam stopped flowing, a steady flow of heavy oil began. The flow was so steady that the area around the well was soon covered by heavy oil. The best course of action appeared to be to connect the well to a flow line and collect the oil. By the time the oil stopped flowing, it was decided to put a pump on the well. Between flowing and pumping, the well produced a tremendous quantity of oil —much more than anyone would have anticipated from the tests that had been proposed."

"Thus the steam soak (also known as the 'huff and puff' or cyclic steam injection) was invented. Call it what you will; it is today one of the most powerful and economic techniques for producing oil."

"Use of steam for the production of heavy oil in California soon followed. Production reached a level of 150,000-200,000 barrels per day within a few years, thereby reversing the overall decline of oil production in that state, and restoring California production to about one million barrels per day. In Venezuela, production has reached levels on the order of a half million barrels of heavy oil a day. However, in Canada, where I found myself in 1962 proposing a 36-million barrel a year plant, the Alberta government decreed that heavy oil production was inimical to the best interests of that province. They did not believe our forecasts of demand nor our forecast of diminishing discovery of reserves. Our plan was judged to be overall detrimental to the normal cycle of exploration and development."

"Today (June, 1980), heavy oil production is an established art; yet production of heavy oil in the United States and Venezuela is not much greater than it was in 1965. In Canada, heavy oil (tar sands) production is being realized by mining, and in-situ production is still in its infancy."

"One final note. . . . We had no insight about the possibility of the steam soak when we went to the field, and there was virtually no way we could have conceived of the steam soak short of working in the field. In this story there is a lesson of empiricism that I think should be heeded. Research is needed." But it must be carried out at a very sophisticated level to be successful. "Sometimes, it will be necessary to conduct very expensive and well monitored field operations without the benefit of conclusive experimental results in the laboratory. This must be done on the strength of intuition and inference of trained, yet visionary technologists."

As opposed to steam soak or huff-and-puff, steam drive is a continuous process, much like waterflooding. Ideally, steam is injected into wells surrounding the producer, creating a saturated zone. As steam moves away from the injector, its temperature falls and it expands with the pressure drop. At some distance from the injector well, the steam condenses and forms a hot water front. In the steam zone, oil in the rock pores is distilled by the steam and displaced by its pressure. In the hot water zone, the oil viscosity is reduced greatly, and it expands with temperature, further increasing oil production.

About half of the steam operations are now continuous steam drive (the other half being huff-and-puff) and the proportion is increasing. However, there are advantages to letting the operation heat soak at periods, so that some steam drive operations are intermittent from time to time.

Fireflooding

Although fireflooding is also used to reduce the viscosity of the oil in the ground (in situ), it is a totally different mechanism than stream drive. Like continuous steam drive, fireflooding requires drilling auxiliary injection wells near the producing well. A fire is lighted in an oil-bearing formation at the selected level in an auxiliary well and air is continuously injected to support combustion.

As the fire front advances through the formation, heat ahead of the front reduces the oil's viscosity, while pressure from the air supply and the combustion gases drive it toward the producér well. Fireflooding requires considerable power for the air compressors, which are often electric-driven, and consumes about a third of the oil in the ground in the combustion process, actually the coke deposited by the crude oil as it moves ahead of the combustion front.

Many factors limit the suitability and the effectiveness of a fireflood operation. The fuel concentration deposited in the reservoir rock as the oil departs, along with the air supply, determines if enough heat can be generated to support combustion. Oils that leave very high deposits are uneconomic because of the larger air quantities (and pumping costs) they require. If a low concentration of coke is left, the combustion process may not propagate. Formations less than ten feet in thickness generally produce insufficient oil, or absorb too much heat, to be economical.

Since compressor investment and power used are the two largest costs in a fireflood operation, generally the economics are determined by the amount of air required for the oil produced. Successful operations have air-oil ratios of less than 20,000 SCF/bbl (standard cubic feet of air per barrel of oil produced).

In the dry combustion of fireflooding, more than half the heat is contained between the combustion front and the air injection well. Wet combustion is a process in which water is injected along with the air. Water then transfers this available heat forward toward the production front, increasing the size of the steam zone downstream of the advancing combustion zone. "This water injection can have a significant impact on the air/oil ratio. Heat scavanging, via waterflood after in situ combustion is another approach to more effectively use the heat contained in the reservoir rock."[5-7] Figure 5-1, taken from that reference, shows the relative activity in cyclic steam, steam drive, and fireflooding since 1970.

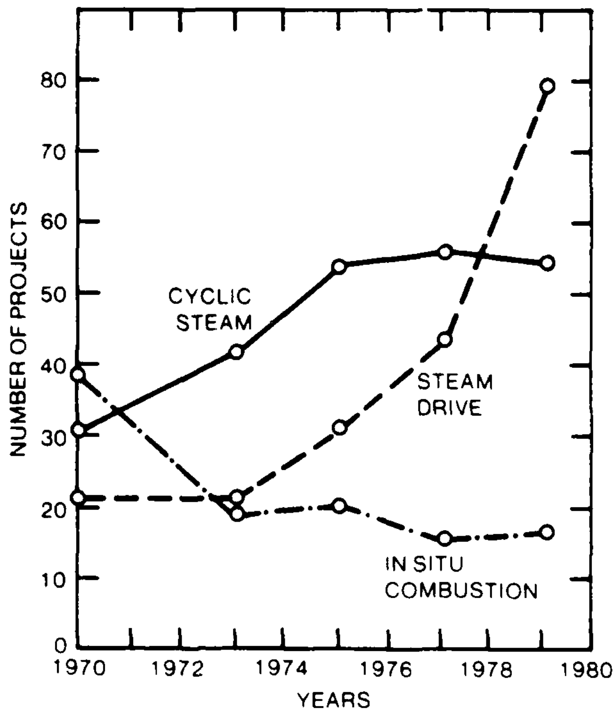

Figure 5-1
Number of Thermal Recovery Projects in U.S.

The largest EOR operation today is Getty's steam soak/steam drive Kern River field in Kern County, California, which has been producing over 50,000 b/d. Getty's Bellevue field in Bossier Parish, Louisiana, is a combustion project yielding over 2,500 b/d. Other successful EOR projects are more in the range of only 400-600 barrels per day.

Miscible Fluids

Thermal methods, or steam and fireflooding together, account for about three-quarters of EOR production in the U.S. Where thermal methods are used to produce heavy oils, the other EOR methods are used for producing light oils after water flooding has been completed. Thus, in the U.S., the potential for EOR production quantity is much greater for the non-thermal methods, to increase yields in the light-crude fields where production has been terminated.

Elkins[5-4] shows this graphically in Figure 5-2. His base production, "Old Oil Primary & Secondary," corresponding to Hubbert's projections, shows U.S. production declining after 1970 and nearing final depletion in 2000. His second segment is primary and secondary oil from new discoveries, more optimistic than Hubbert. His third segment is "North Slope," and his final segment shows the contribution from enhanced oil recovery.

Keep in mind that this chart was presented in the middle of 1980, when only the daring suggested that there may be ways of recapturing the U.S. production level of 1970. So Elkins would expect EOR to exceed the output of Prudhoe Bay and, more important, would show increasing production out beyond 2000.

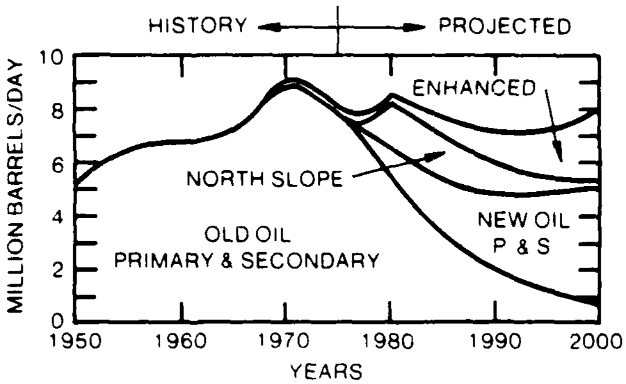

Figure 5-2
Projected USA Crude Oil Production Rate

rather than declining. By 2000, his projection would have EOR production up to nearly three million barrels a day (MMBD), about ten times its rate today. And he points out that 3 MMBD represents only one-fifth the reasonable target for EOR.

In Figure 5-3, Elkins shows how he would expect the EOR contribution to break down among thermal, CO_2-miscible, and chemical. The latter two deal with light oils. Since thermal EOR now accounts for about three-quarters of U.S. EOR production; EOR from light oil reservoirs has not yet reached a significant commercial level.

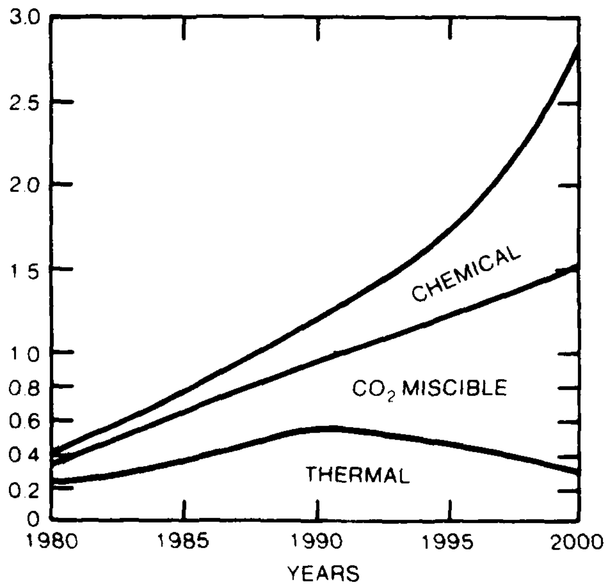

Figure 5-3
Projected Split of EOR Between Methods

"A ***miscible*** displacement of fluid from porous material occurs when no interface exists between the driving fluid and the driven fluid because of the miscibility, or mutual solubility of the two fluids. This is in contrast to immiscible displacements such as water or low-pressure gas driving oil, where identifiable interfaces exist. In the miscible displacement of oil by another fluid, interfacial tension and related capillary forces between the two fluids and the rock are absent, so the driving fluid can totally displace the residual oil in place in the rock entered by the driving fluid. Because of this, miscible displacement has obvious technical potential for enhanced oil recovery."[5-8]

The first efforts with miscible displacement began in the 1950s with propane, methane (natural gas) and with methane enriched with liquid petroleum gases (LPG). These methods are apt to be expensive, particularly when the driving agents can be marketed directly on their own.

An alternative that promises to be cheaper is carbon dioxide or CO_2 injection, which has been investigated for more than twenty years. Carbon dioxide is the gas that freezes into dry ice without passing through a liquid phase. Under pressure, however, CO_2 can exist as a liquid, and at the temperatures and pressures encountered in many oil formations CO_2 remains a liquid.[5-1] Liquid CO_2 is miscible with crude oil, but not in the same sense that gasoline or propane will mix with crude oil completely and in all proportions.

Instead, CO_2 develops what is called multiple-contact or dynamic miscibility within the rock formation. CO_2 dissolves in the oil while at the same time extracting hydrocarbons from the oil.[5-9] At high pressure, the miscibility pressure, this mass transfer of hydrocarbons proceeds rapidly and very efficiently. Stalkup shows in Figure 5-4 that the displacement efficiency can be high enough to recover up to 90% of the oil in place. Some report that, if fully effective, CO_2 dissolves in the oil, expands it, and reduces its viscosity to near zero. Under ideal conditions, it could strip all but 2-3% of the oil in a reservoir.

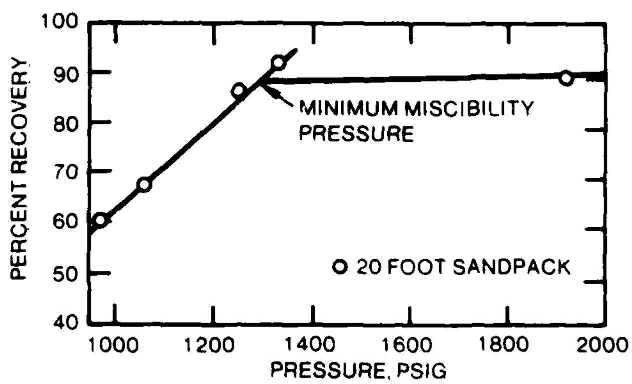

Figure 5-4
Displacement of a West Texas Oil by CO_2 at Various Pressures

One may dream by applying this factor to the world's unproduced light oil reserves. Here is some potential to get excited about. But, although the displacement is miscible, several mechanisms can cause oil saturation to be left in rocks swept by CO_2. At low temperatures in some basins, such as the Permian Basin in West Texas, multiple phases are formed when the CO_2 and oil are mixed. Under some conditions four phases — two liquids, a gas, and a solid — are in equilibrium. This multiple phase formation is not yet well understood.

But carbon dioxide has been tested successfully down to 12,700 feet over a range of temperatures and over a wide range

of crude oil viscosities CO_2 appears to be useful over a much wider range of conditions than the other methods. Some have said that the application of CO_2 is limited more by availability of the gas than by any other factor.

Large quantities of natural CO_2 have been tapped during the last few years in southern Colorado and a cooperative pipeline will be transporting it to the West Texas and New Mexico fields. More recently, CO_2 resources have been struck in Texas. Each find seems to have discovered more CO_2 than required by the oil company needing the CO_2. From a technology limited by availability of CO_2, the situation seems to be improving rapidly. In the future, this area of West Texas-New Mexico could again become a major oil producer.

Surfactants, Chemicals and Micellar-Polymers

Just as it is difficult to wash out oil that has saturated a garage floor, water is not ideal for flushing oil out of rock. Water tends to flow through the freer channels of the rock, bypassing oil in the smaller channels, which remain isolated.

Promising agents include detergents, surfactants, and chemicals (caustic, base or alkaline) which react with chemistry within the oil-bearing formation to form surfactants in place.

"Certain chemical solutions, which are similar to detergents and called surfactants, are capable of reducing the surface tension between water and oil, thereby permitting the water to be more effective in driving out the oil. These chemicals are made up of molecules which have one end that is repelled by water while the other end is chemically attracted to water. When a surfactant is mixed with oil and water, some ends of the molecule orient themselves toward the oil while the other ends are attracted to the water, and the oil is organized into tiny droplets called micells."

"Because the micells are much smaller than the particles of oil that form a mixture of pure oil and water, they are much easier to move through a rock formation."

"After the surfactant has been injected into the ground in much the same way that water is injected for waterflooding, specially prepared polymer solutions are injected to act as 'pistons' to drive the micells through the formation. Polymer is a general term for a large organic molecule."

"The polymer solutions used in enhanced oil recovery are carefully selected to relate directly to the density and viscosity of the micellar mixture of oil and water. Finally, water is used to push the polymer solution, which in turn pushes the micellar solution and the oil toward the producing wells."

"The micellar-polymer process is much more expensive than waterflooding, and it has been tested only in small-scale field tests. . . . It takes a long time before the results of a micellar-polymer experiment are fully known. Typically, the lifespan of a micellar-polymer flood study is about five years. More than two years may pass before there are definite signs of success or failure."(5-1)

Alone, "Polymer flooding does not lower residual oil saturation significantly. It improves oil recovery beyond water flooding by increasing the volume of the reservoir contacted. Therefore, polymer flooding is applied most effectively in the early stages of a waterflood while the mobile oil saturation is still high. The higher the producing water-oil ratio, the higher the risk will be of failure, as indicated by some of the field tests."(5-10)

So polymer flooding could be used twice; once during the straight waterflood phase, and later to drive through a charge of surfactant.

Mining for Oil

Considering that mining of oil shale appears to be a feasible operation and that liquid oil is bound in the pores of rock as is the solid hydrocarbon (kerogen) in oil shale, it may not be too outlandish to consider mining oil-bearing rock or heavy-oil bearing sands. This possibility has been studied in some detail and some pilot operations have been tried.

Energy Development Consultants, Inc. and Golder Associates jointly studied petroleum minimg for about a year under a grant from the Bureau of Mines.(5-11)

One concept is to sink a shaft and system of tunnels below a bed of heavy oil, then drill short shafts upward into the formation, and drain it by gravity. Study indicated that the economics could be very attractive, but the technical risks are high. There is the question of drilling through pressurized reservoirs. It is believed possible with careful techniques, but it is not yet proven practical in the field. One of the problems is to know precisely where the bottom of the reservoir lies and how closely below it the tunnels can be cut. It may be necessary to run the tunnels as close as fifty feet below the bed to make the process economically competitive. Since it is expected pressure locks will be needed in the tunnels for safety and pressure locks cost $150,000 apiece, the costs could mount rapidly.

Another concept is, instead of moving the oil horizontally to a well, where it is lifted vertically, to move the oil vertically. This might be done in a shallow formation by stripping off the overburden and then laying a stabilization bed of hot water on top of the reservoir. If steam is injected below the bed to reduce its viscosity, the oil should rise through the water, to be collected off the surface.

Mining engineers contend that this technique could be used in deeper deposits by exposing the top of the formation and going through the same process. All the knowledge on surfactants and density changes could be used to enhance this type of oil production.

Most of the companies which have studied these mining operations apparently conclude that other EOR techniques may be more attractive. At least, they are generally judged less risky. There are cost trade-offs, however, which are interesting. Balanced against the cost of mining is the number of pumping units needed to operate a field from the surface, about 625 installations per section of land. The mining operation may require even more capital costs, but lower operating costs per barrel. If the percent of oil recovered is increased from 33% to approximately 90%, as compared to a representative 40% for EOR, the costs would be spread accordingly.

Where recovery costs are marginal, "stripper" wells move into and out of operation, as oil prices increase and stripper costs increase successively. In a mining type of operation, the low operating costs would remain nearly fixed and the economic limit should be predicted with more confidence, if the costs can be estimated with any confidence in the first place. There are so many factors, especially including taxes, that enter into a comparative analysis, that it is not surprising the special conditions for attractive mining have not taken hold. When marginal costs on other petroleum climb higher, perhaps costs of mining various formations will be found practical.

The overall effect on the market and, in turn, on aviation fuel prices, is apt to be slight. The significant fact is that, as fuel and crude prices rise, there are techniques which can and will bring additional oil to market. Or, conversely, if reduced regulations and taxes can relieve some of the marginal oil production costs, more oil should be offered to the market and prices should be reduced.

Aviation users should be interested because some developments or improvement in these relatively remote or indirect areas could end up reducing the price of aviation fuel.

Problems of EOR Production

Many of the production problems associated with various EOR methods could be seen or inferred as the methods were described. Like wildcatting, EOR is a financial risk. One risk absent in EOR is the presence of oil; oil is already known to be there. It has already been produced by primary, probably secondary, and possibly by some previous tertiary process.

Generally, well logs are available, describing the geology of the area. The type of oil is known, as well as its chemistry, and the chemistry of the formation may be known to varying degrees. Often, a good idea of the quantity of oil is known. What is the risk?

A well may have delivered primary production near the edge of a blocking fault without any apparent difficulty. But a fault between a producing well and one or more of its injector wells may mean that the injection will be blocked and never reach through. Conversely, there may be a fault or fissure where all the injection disappears inexplicably forever. Underground geology must be known with some confidence before investments are made for the injector wells and the injection equipment. There are always ample opportunities for unknowns.

Even fireflooding, which burns the energy within the formation, may require so much air injection that oil producers joke there is no place to put all the "iron" (pumps and equipment) on the land above.

And visualize the planview of a producing well surrounded by injecting wells. The injected fluid must flow toward the producer, not in other azimuths (or into some fracture, as has been mentioned). Looking at it in profile as well, the injected fluid should sweep all the oil-bearing formation depth as it approaches the producing well. Often, due to differences in density or viscosity, the injected fluid will probe out in fingers of least resistence. It may easily short-circuit or blow-through to the producer while sweeping a minimum of oil. Slugs of polymer fluid are supposed to reduce this tendency.

One of the real financial risks is time. Oil must be produced at rates sufficient to pay off the investment. Some EOR processes need time to take effect. One professional oil consulting firm has seriously proposed injecting fields with the appropriate fluids (selected by analysis and tests), then sealing off the field for about five years to let all the oil-loosening processes operate and stabilize. After the five-year period, the field would be opened and produced. In addition to anxiety and hang-fire plans while waiting to see if the field will produce, high interest rates, land leases and taxes discourage this sort of approach.

Also, suppose a misjudgment was made in the chemistry, geology, rheology, thermodynamics or economics of the analysis. Five years is a long wait to find out. Further, during the wait, a rise in taxes or adverse regulations could render the operation uneconomical before production can begin!

Steam drive projects, and even underground combustion in fireflooding, have created environmental and emission problems. Some projects have had their production limited or have been shut down because of the environmental costs. Steam generated on the surface cools rapidly as it is injected down into the well and rock so that, generally, steam is not practical at depths below about 2500 feet.

Combining the combustion techniques learned in rocket engine design and compact mechanical engineering from nuclear weaponry, the DOE Sandia Laboratory has designed and built a "down-hole" steam generator which generates its steam at the selected depth in a well. This concept offers the possibility of delivering high-quality steam at greater depths with reduced heat loss, also containing the combustion/emission problems. A test operation is currently under way in downtown Long Beach, California to try out this promising equipment.

Many more problems and their details are available in the literature. The point is that EOR is generally regarded overall as risky as wildcatting. But wildcatting is attractive to some as a more known quantity, to others as a quicker return on the investment, and to all as a better tax situation.

EOR Costs

EOR is almost intrinsically limited to fairly shallow wells in many techniques because, if a formation is at 3,000 feet or more, auxiliary wells cannot be drilled at a dense enough well spacing to recover the oil economically.

A fairly rough indication of how EOR is regarded is given by the report of the ***DoD Shale Oil Task Force***, 5 October 1978,[5-12] which will be discussed further in Chapter 8. But it may be noted here that the report rated a variety of alternative fuels versus conventional petroleum as a source for military jet aircraft fuel. Jet fuel from conventional petroleum was listed at $18.19 per barrel at 1978 prices. By comparison, shale oil and tar sands came out at $23.00; coal liquefaction at $33.00; and tertiary recovery at $33.50 per barrel of jet fuel. EOR comes fairly far down the list if produced in the quantities needed.

This would confirm that our present EOR production in the U.S. is only skimming off the lower-cost operations. Or, the other way around, that EOR costs are very high versus conventional production, or even versus U.S. shale oil, if large quantities or production rates are required.

It will be recalled that some EOR spokesmen estimate that 900,000 b/d of EOR could be produced if regulations and taxes were more comparable to that for new oil. The DOE has observed that it takes on an average up to six years after primary and secondary production of a field have been halted before tertiary operations can begin, largely because of the regulatory delays. Tertiary production is inherently slow because of studies and tests required before the investment should be made, as well as the time for the operation itself. Where well costs in an oil field used to average about $11,000/acre, EOR now runs over $114,000/acre.[5-13]

Once the investment is made in injector wells, pumping plants, etc., field production must be profitable long enough to amortize the investment. In California in 1979, it was costing $9 to produce a barrel of heavy oil with thermal extraction, while the average sales price was $8.50. At that time, 5,800 wells shut down in California.[5-14]

Not an inconsiderable factor is the skilled and specialized manpower required, the laboratory support, and the close management attention and control which must be applied in an EOR program. In a business with rapid expenditures and multiple options, oil producers must keep good track of an EOR project to catch it quickly before it develops into a runaway loss. How does one determine when he is throwing good money after bad?

Where conditions are right, EOR can be profitable. Professor Henry J. Ramey of Stanford says, "The in-situ combustion operations that started in the early 1960s are still operating, and all are profitable. The primary advantage is the very high oil recovery, perhaps 80 percent in ideal situations."[5-15] This is true even though the fields he refers to require about one-third to one-half the energy of the oil produced to generate the steam drive.

When it comes to chemicals, the risks, requirements and costs seem to defy the possibilities for success. One cubic foot of rock presents a surface area equivalent to 20-25 football fields which must be wetted by a detergent to release the adhering oil.[5-16] Where water drive costs about five cents a barrel to produce, successful chemical treatments cost up to $15 and more. If much more, the answer is simple; the reservoir is abandoned.

The chemistry of the oil, its resident water, the drive water, the reservoir rock (including its sands, clay, etc.) all must be compatible with the charging fluid. Also, chemistry must be reasonably uniform throughout the oil field. In addition to chemical and geologic structure of the reservoir, its microscopic, ionic and electrical conductivity characteristics must be understood. Chemicals must be relatively cheap and effective at fairly low concentrations in water. Chemical prices must not rise more rapidly than oil market prices, which may be artificially held by regulations or taxes.

The EOR process, and the decision whether or not to proceed, can become extremely complex.

Future of EOR

It would be pleasant to be able to say that the future of EOR is as rosy as its vast potential. The fact that EOR production has not increased in volume significantly over more than ten years says a lot, particularly since the price of crude oil has increased so much during that time. Referring again to Figure 1-1 or Figure 4-5, one could not expect a mere future price rise to "liberate EOR."

Similarly, except for a ***real*** breakthrough, technological development is not likely to overcome most of the EOR economic negatives. Technology, however, may whittle away at the costs and nudge some operations into the profitable catergory. These developments may be significant to individual producers, but are not likely to affect the petroleum supply picture appreciably, much less lower the price or increase the availability of jet fuel.

At the 7th Energy Technology Conference in Washington in March, 1980, some participants expressed the opinion that U.S. EOR had already peaked and would decline in the future, in spite of the then recent sharp rise in crude oil prices.

Thermal recovery continues to be the dominant mode for EOR. The ***Oil and Gas Journal*** reported in their EOR feature issue, March 31, 1980, that steam accounted for 77% of U.S. production, up from 67% in their prior report of March 1978.[5-17] This means that mostly heavy oil is being produced from shallow wells and that the chemical approaches for extraction of light oil are generally too costly. But light oils are a significant proportion of our unproduced resources.

For those interested in more or later information, the ***Oil & Gas Journal*** April 6, 1982 issue again features EOR.

Although a down-hole steam generator may improve the thermal process and extend it to greater depths, while CO_2 may make light oil extraction more attractive, the fact remains that EOR is difficult at medium or great depths because of the cost of injector wells.

But all the technical advancements realized or imagined for the future seem woefully dominated by regulatory and tax disincentives. Taxes and regulations continue to favor new oil over production of that already found. Even if an EOR venture is forecast to be profitable, when any producer has a new oil prospect which promises to be more profitable, he will undoubtedly defer the EOR until later. The EOR project will probably have to appear a clear winner, with substantial margin, before it can justify the risk of resources it will require.

Without going into all of the particulars, a few comments will give an idea of the tax problems faced by oil producers and, particularly, EOR. From a reference written by accountants to guide those concerned with federal taxation[5-18] "In general, from the producer's point of view, the imposition of a windfall profit tax on the sale of crude oil has the same economic effect as continued price controls but at a higher controlled price. However, for any oil that has not been subject to price controls, the tax has the effect of a price rollback on the producer."

The windfall profit tax (WPT) contains interesting ramifications: "The full amount of state severance tax applicable to a barrel of oil is not fully deductible from the selling price for purposes of computing the windfall profit tax, although it is fully deductible for purposes of computing federal income tax." Certain tertiary methods can be self-certified by operators and a petroleum engineer. Others must be certified by DOE, the USGS or a state regulatory body. "Qualification will be lost if the project is discontinued."[5-18] The IRS issues advanced determination of the project's WPT status. This determination, naturally, requires application and submittal of the appropriate information.

Definitions get sticky among Tier 3, Tier 2, and Tier 1 oils, their base prices, and whether a well is a "stripper" or not. Since a stripper well is one produced . . . "at an average daily rate of 10 barrels or less per well during any twelve consecutive months after 1971 . . .," there is an incentive to hold low-producing wells to the 10 b/d level and qualify for the more favorable stripper price. "Due to the fast moving pace of price changes during the latter half of 1979, several significant problems are encountered in applying the statutary formula." There are difficulties in definitions between "pools" and "fields," to which different tax conditions apply. "The uncertainty and confusion caused by the ambiguous concepts lay a foundation for inevitable controversy and litigation."[5-18]

A complete compendium of the entire energy tax and regulatory structure, surprisingly brief because it offers no analyses, conclusions or recommendations, is given in Reference (5-19). Some interesting conclusions are given by the Interstate Oil Compact Commission,[5-20] such as: "The Windfall Profit Tax becomes a tax on salt water production from stripper wells . . . exceeding $800 to $2,400 per well per month. . . . Nationwide the Windfall Profits Tax on stripper crude oil is forecast to ***prevent*** the additional recovery of at least 490 million barrels of crude oil due to a reduction in economic producing life of producing oil wells. Exemption of stripper wells from the tax has the opposite effect."

The report goes on to say that the immediate effect is to reduce domestic production by approximately 131,480 b/d and that the value of the reserve thus lost is $17.16 billion.

H.J. Haynes, Chairman, Committee on Enhanced Recovery Techniques, National Petroleum Council[5-21] sums it up briefly and unemotionally: "Enhanced recovery processes are inherently high-cost methods designed to recover oil which is left in the reservoir by lower-cost conventional recovery methods. These high-cost processes are not widely used at present because current domestic oil prices and other economic factors do not permit profitable application, even when they are technically successful."

Robert P. Murray of Cities Service says EOR is, ". . . like cleaning tar from a baby. It's sometimes easier to have another baby."[5-13] Especially since a new baby also brings a tax break!

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Chapter 6

Petroleum Refining and Aviation Fuels

Board Room Briefing No. 6

1. To provide more jet fuel from a barrel of crude oil and to reduce pressure on jet fuel prices, oil companies particularly have suggested that aviation Jet A (kerosene) fuel specifications should be extended on both the lighter and heavier ends.

2. Extending the lighter end (lowering the flash point) of Jet A would introduce no performance or equipment problems. One expects a more volatile fuel to be less safe, but experience is not entirely conclusive on that point. Gasoline and other volatile fuels are used regularly and safe handling methods are well established. U.S. aviation equipment is also certificated to operate on Jet B, which has no flash point requirement and is closely related to gasoline.

3. Because much less static electricity is generated in pumping Jet B than Jet A, this quality tends to offset the volatility disadvantage of Jet B. Anti-static additives can decrease this problem for both fuels, while electrical grounding procedures are standard during fueling operations. It is generally agreed that Jet B is more hazardous in a crash fire or an in-flight lightning strike. A mixture of Jet A and Jet B is as hazardous as Jet B; in some conditions probably more hazardous.

4. Recent decrease in U.S. autogas consumption and future predictions for its further strong decline suggest that the lighter petroleum fractions will become increasingly available. In opposition, there is also evidence that demand for light naphthas will increase as feedstocks in petrochemical operations. But overall, it is expected that future fuel trends, including periods of crude-oil supply disruptions, will provide more light fractions for aviation turbine fuel.

5. Extending Jet A specifications to include lower fractions introduces an entirely different set of considerations than the lighter fractions. Lower fractions tend to thicken and solidify in the low temperatures at high altitude; a change in cruise altitude can cost significant fuel consumption. Lower fractions cause harder starting, have more tendency toward fuel-system fouling, and burn with a more luminous flame. This higher radiant heat is more hostile to engine burners, fuel nozzles, turbine blades, and maintenance costs.

6. Prolonged use of heavier fuel could require modifications to aircraft engines and fuel systems, including adding insulation or heaters to fuel lines and tanks. The new-generation aircraft, not yet delivered, would encounter similar problems: higher capital costs, penalized payload or range, and higher fuel consumption.

7. Refiners have not really offered improved fuel availability or lower prices if Jet A specs were broadened; they infer only that availability and price pressures will be eased if the present standards are relaxed. It is not evident that the costs of aircraft modifications or of new equipment, or even of degraded aircraft performance, would be offset by lower fuel prices. It is doubtful any price reduction could be assured over the amortization life of capital investment.

8. A heavier Jet A would compete more with diesel, heating and other middle-distillate customers. This market is growing and is forecasted to expand further. Lowering the heavy end of the Jet A spec could increase its market competition.

9. To process lower-grade feedstocks and deliver more attractive finished products to the market, many refiners are improving their plant flexibility. These refiners will have little difficulty in producing high-quality aviation fuels within specifications at competitive prices. The future trend may be stronger in this direction. Developments in catalytic processes promise to increase refinery capability further and to eventually decrease costs of special operations. Even super-grade fuels may become feasible in a few years.

10. Shale oil processed into jet fuel yields a high-quality product which receives no advantage from relaxed specifications.

11. In summary, there appears to be little incentive for the aviation industry to embrace a degraded fuel specification. On the other hand, it should be valuable to know the opportunities and penalties for using degraded fuel temporarily during near-term crude-oil disruption emergencies.

12. High price and limited availability of aviation gasoline are plaguing general aviation operations in the U.S. and abroad. There may be some partial relief, at least for recreational flying with lower-octane gasoline, but there is no encouragement in the area of high-octane aviation gasoline. While aircraft dependent on avgas will continue to find fuel, the supply and price difficulties may become chronic, particularly outside the developed countries. New aircraft and engines designed to operate on jet fuel should enjoy significant fuel price and availability advantages.

Introduction

In previous chapters we have been concerned with the world fuel supply/demand balance, aviation fuel in the market, and with resources and production of petroleum. An important component of aviation fuel price and availability is the petroleum refining process and specifications for fuel.

In the past, approximately three-quarters of the cost of jet fuel has been in the crude itself, one-fourth in its processing and distribution. Many refiners believe that jet fuel processing costs

will increase faster than crude costs and that it will be increasingly difficult for them to deliver the quantities desired within the existing specs. With regard to processing costs, jet fuel is expected to become more like diesel, gasoline and heating oils, for which refining costs are a larger percentage of their total cost.

Aviation fuel naturally has to compete with the other refinery products and customers, both in fuel price and in specifications. The two factors, refining and specifications, will be discussed in this chapter only enough to indicate how they influence price and availability, and how these effects may vary in the future.

The subject of aviation gasoline had been intended to be reviewed in considerable detail in this report, because both its price and availability have become so unfavorable in recent years. Gasoline users probably feel the picture is poor, that the future looks worse than the past, and that aviation gasoline is one of the most critical problems facing those that must use it. There may be some relief in the situation for low-octane, recreational users, but the world supply of high-octane aviation gasoline is likely to remain erratic.

In the long run, avgas is likely to become a refinery specialty product; some say it has already reached that status. It appears desirable to design new equipment for operation on more universal fuel, such as Jet A, Jet B, or both.

As we have seen, all aviation fuel accounts for only about 6% of U.S. petroleum. In turn, aviation gasoline makes up only about 5% of the aviation fuel used; the remaining 95% is jet fuel. But this relatively minute quantity of gasoline is important to the U.S. economy and to U.S. aviation. Chapter 1 briefly outlined some of its characteristics.

The whole picture of general aviation need not hinge, however, on aviation gasoline. In addition to the brief discussion of gasoline in this chapter, general aviation readers may be interested in a section of Chapter 8 on alternative fuels, which discusses other fuel and propulsion options for small aircraft. To this author, it appears that liquid methane is an attractive early alternative for all octane requirements in short-range operations. Once the fuel system modifications have been installed, liquid methane appears to offer substantial fuel cost advantages.

This chapter, then, is divided among petroleum refining, jet fuel specifications, and aviation gasoline.

Petroleum Refining

Petroleum refining will be outlined here only to indicate its influence in aviation fuel price and availability, aviation's competition with other refinery products, the possible effects of crude oil characteristics and trends, as well as effects of refinery operations on the future of aviation fuels. The basic capabilities of refineries are also important in understanding alternative (synthetic) fuels for aircraft.

It is even appropriate to have some minimum understanding of petrochemical operations, since developments and alteration in their feedstocks may affect the petroleum market, compete with it, or release stocks for aviation fuel. The following account refers liberally to References (6-1) and (6-2).

The name organic chemistry, the chemistry of carbon compounds, is derived from organic, or previously living organisms. For crude oil and other fossil fuels, this is particularly appropriate because it is believed that these hydrocarbons were deposited as the fossil remains of prehistoric life. (Interesting possible exceptions are methane hydrates and deep-earth methane, which are discussed in Chapter 7.)

Hydrocarbons are organic compounds which contain only hydrogen and carbon. The most fundamental hydrocarbon molecule consists of one carbon atom with four hydrogen atoms attached. This molecule is CH_4, methane, natural gas. Note that methane is the hydrocarbon with the most hydrogen atoms per atom of carbon; it therefore contains more Btus of combustion energy per pound than any other hydrocarbon.

There are literally millions of more complicated ways in which hydrogen atoms can be attached to combinations of carbon atoms and crude oil contains many of them. In 1928 a research project was established to isolate and identify the constituents in crude oil, there being many in addition to the hydrocarbons. In 1968 the project was put on the back burner because it appeared that the task literally never could be completed. Crude oil analysis still goes on, but now it uses gas chromatology (GC), mass spectroscopy (MS) and nuclear magnetic resonance (NMR). Composition can be determined up through C_9 and C_{10}; the compounds can be typed up to about C_{40}.[6-3]

"The various pairings of hydrocarbons make up each of the different petroleum products. It is the job of the refiner to combine the hydrocarbons in crude oil into these products."[6-3] He may achieve these results by separating out various groups of hydrocarbons or individual hydrocarbons, by cracking large molecules into smaller ones, or by polymerization, combining smaller molecules into more complex structures.

He may introduce other elements, such as nitrogen, to synthesize ammonia or other organic materials which are not hydrocarbons.

But the primary job of a refinery is separation of the crude feedstock into its basic hydrocarbon components, which is done largely through distillation. This may be called fractional distillation since the purpose is to separate the crude stock into its various fractions, by molecular weight. The earlier refineries and some of the unsophisticated refineries today perform only fractional distillation. Many products, including some gasoline and jet fuel (kerosene), may be marketed straight as they come from the fractional distillation tower. This may be done, however, only if the crude oil had suitable characteristics in the first place. A distillation process can only separate a feedstock into the components it already contains.

In distillation, the important factor is the boiling point of each fraction because that is how the separation is made. The range of boiling points is great, as low as -250°F for some components and over 1,300°F for others. Those with high volatility are called light ends and those with low volatility (like asphalt) make up the heavy ends. Depending on the product slate the refinery wants to produce and the crude oil it will be supplied, its fractionating tower is either built or adjusted to separate out the components according to their appropriate boiling points. After separation, components can be recombined or blended to produce intermediate products.

Fractional distillation begins by heating the crude to the boiling point of the heaviest product to be produced; most of the crude is vaporized. By progressively cooling and condensing the vaporized mixture as it progresses up the fractionating tower, components are drawn off at appropriate temperatures as the lighter fractions proceed to the higher levels. The lightest liquids are taken off at the highest level and the gases come off at the top.

Inside the fractionating tower is a stack of trays in which the vapors condense. The arrangement is shown in Figure 6-1.[6-1] As shown in the small detail, vapors pass up the tower through short tubes in the condensation trays. A bubble cap on top of each tube requires the vapor to pass down through the condensate in that tray. Molecules of the same weight (boiling temperature) as the liquid in that tray will condense and join the liquid. Lighter molecules bubble out from the liquid and pass on up, through the tubes to the next higher tray.

BOILING RANGES OF PETROLEUM FRACTIONS			
RANGE OF CARBON ATOMS	BOILING RANGE	NAME OF FRACTION	PRINCIPAL USES
1 to 5	BELOW 40°C (104°F)	GAS	FUEL
6 to 10	40° TO 180°C (356°F)	GASOLINE	FUEL
11 TO 12	180° TO 230°C (446°F)	KEROSENE	FUEL CRACKING STOCK
13 TO 17	230° TO 305°C (581°F)	LIGHT GAS OIL	CRACKING STOCK DIESEL FUEL
18 TO 25	305° TO 405°C (761°F)	HEAVY GAS OIL	LUBRICANT STOCK
26 TO 60	405° TO 515°C (941°F)	RESIDUUM	BRIGHT STOCK WAX RESIDUAL OIL ASPHALT

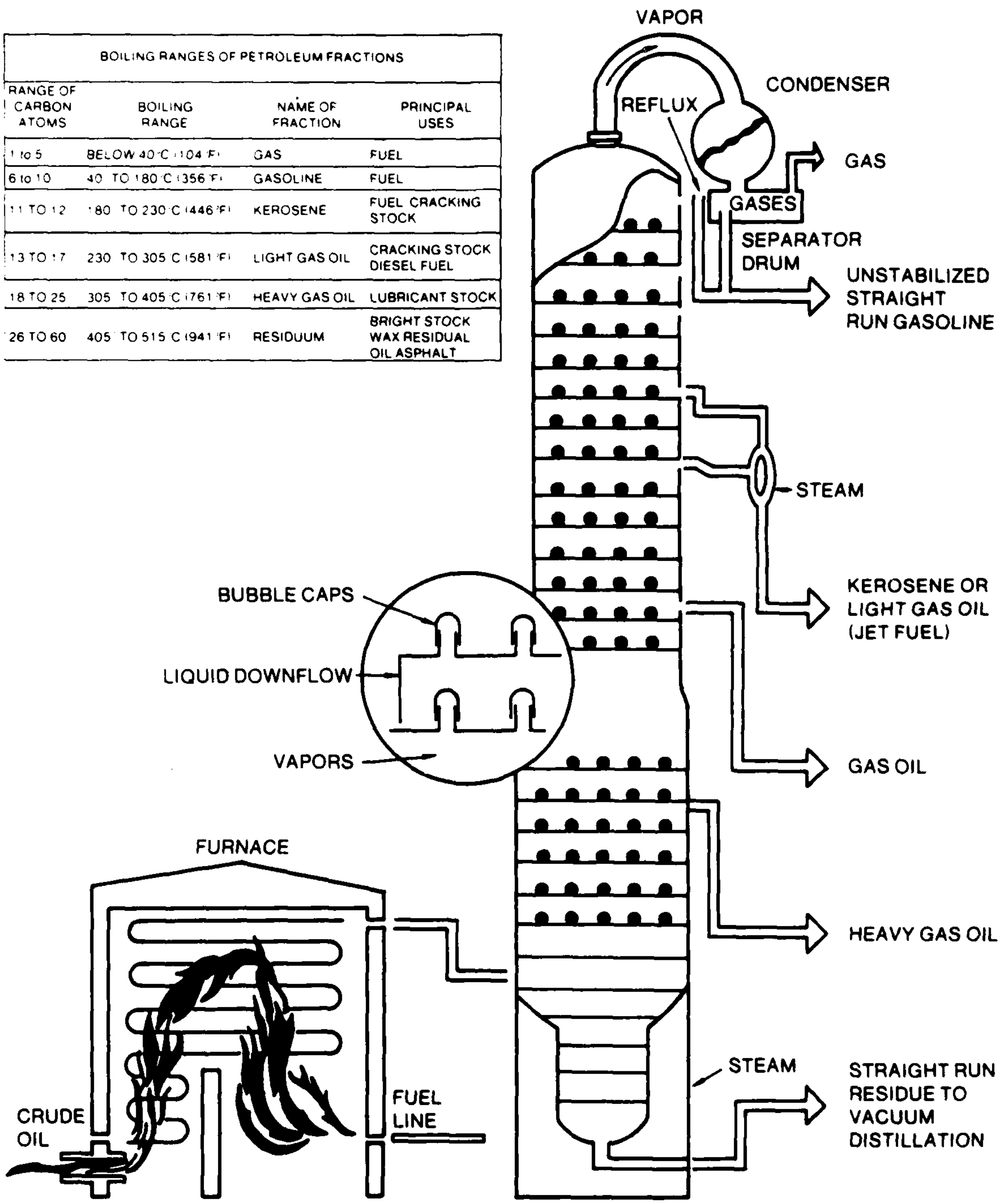


Figure 6.1
Typical Modern Fractionating Tower

Liquid which overflows from a tray drops down to the next level below, where it revaporizes. This flexibility in flow rate permits the refiner to continuously take off the fractions he wants at the appropriate levels of the tower without concern about mixing fractions.

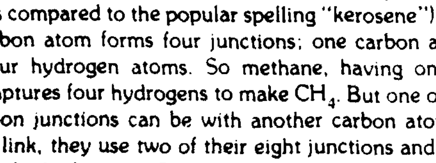
Straight-run distillation is limited in that it may not be able to yield various products in the proportions and quantities needed for the market. For example, a relatively small amount of straight-run gasoline can be distilled from crude oil.

Notice that Figure 6-1 indicates the types of products drawn off at the different levels, as well as the number of carbon atoms in the molecules. It is seen that gasoline molecules vary from 6 to 10 carbon atoms, while kerosene molecules have 11 or 12. (Incidentally, the petroleum industry usually spells it "kerosine," as compared to the popular spelling "kerosene").

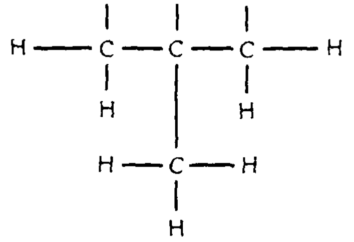
A carbon atom forms four junctions; one carbon atom captures four hydrogen atoms. So methane, having one carbon atom, captures four hydrogens to make CH_4. But one or more of the carbon junctions can be with another carbon atom. If two carbons link, they use two of their eight junctions and leave six available for hydrogens: C_2H_6, ethane. And so on up the line. So kerosene is generally a mixture of $C_{11}H_{20\text{-}24}$ and $C_{12}H_{22\text{-}26}$.

If larger hydrocarbon molecules are cracked into smaller molecules, some carbon-carbon bond(s) must be broken and hydrogen atoms added at the breaks. So cracking requires addition of hydrogen atoms. They can be derived from the same crude stock by stripping some of its carbon atoms entirely of hydrogen, producing coke and free hydrogen. Conversely, if smaller hydrocarbons are combined or polymerized into larger, more complex hydrocarbons, the process will release hydrogen which can be used for other purposes.

One complication which arises in organic chemistry is that the familiar chemical formulas are no longer adequate. Different arrangements with the same number of atoms can result in different compounds. For example, C_2H_5OH may be either dimethyl ether or ethyl alcohol. To avoid confusion it helps to use structural formulas to indicate the atomic arrangement. As an example, butane, which is C_4H_{10}, can be in the form of a continuous carbon chain:



However, another possible arrangement is:



The first form is called normal butane; the second is isobutane. These two compounds with different arrangements of the same atoms are called isomers. With molecules having more carbon atoms, the possible isomers are more numerous.[6-2] Octane, for example, may have 18 isomers; decane may have 75.[6-3] One of the primary groups of hydrocarbons is the alkane or straight-chain paraffin series, which have the general formula $C_n H_{2n+2}$, as described verbally above. Petroleum is the principal source of paraffins and they are separated by fractional distillation. One carbon atom forms methane; two, ethane; three is propane; four is butane; five, pentane; six, hexane; seven, heptane; eight, octane, and so on.

So normal octane is a simple linear chain of eight linked carbon atoms with hydrogen atoms attached. Iso-octane is a more complicated arrangement of the carbon atoms. The original octane engine knock rating came from percentage of the iso-octane, 2,2,4 trimethylpentane, in a mixture with normal heptane at which knock would develop in a standard engine under standard conditions. Normal heptane has an anti-knock rating of 0, while iso-octane is 100. (Normal octane has an anti-knock rating lower than 0).

Although kerosene was shown in Figure 6-1 as having 11 or 12 carbon atoms, it may have as few as 9 or as many as 14. Middle fraction, with molecules to $C_{20}H_{42}$ is sold as *diesel fuel* or heating oil while heavier fractions with molecules above $C_{20}H_{42}$ become gas oils which are cracked to smaller molecules or are processed as lubricant base stocks, waxes, greases or special fuels and fluids. Residium from distillation is sold as heavy fuel oil, tar or asphalt. Processed further it will yield coke, which is almost pure carbon, used for production of batteries, graphite or electrodes for refining metals or chemicals. According to the American Petroleum Institute (API), 95% of each barrel of crude is converted into a marketable product, the remainder being burned as refinery process fuel.

The production of lighter products also lowers the average density so that the **volume** of all products tends to exceed the volume of crude input by as much as 10%. It is important, therefore, to carry out process and economic analyses on a mass basis.

Petroleum cracking was developed to yield more gasoline than naturally occurs in crude oil. This was first done during World War II by using higher temperatures and pressures than in the normal fractional distillation process. Under these conditions, the larger molecules literally fragment into smaller components. When pressure is released and temperature reduced, the hydrocarbons recondense into smaller molecules.

Although the cracking process was ". . . very poorly understood by chemists . . ."[6-2] at the time, cracking units were designed, built and operated on a large scale. "As research provided details on the basic reactions involved, refinements were made in designs and operations." Significant details to be learned included knowledge about the speed of the reaction, how equilibrium of the reaction is reached, the optimum conditions, development and use of catalysts to assist and control the reaction, and so forth.

Catalysts do not take part chemically, but accelerate the reaction by providing a compatible surface or pores where the reaction may take place. Catalytic cracking can be done under much less pressure than thermal cracking and is therefore cheaper. Catalysts range from solids such as alumina pellets, clays and metals (platinum, cobalt, molybdenum) to liquids such as acids.

In addition to more gasoline quantity, cracking produces a better grade of fuel with higher octane rating, especially with catalytic cracking.[6-1]

"Polymerization is the opposite of cracking. In polymerization, smaller hydrocarbon molecules are condensed into larger gasoline molecules. Before polymerization was introduced, most of these smaller hydrocarbons were regarded as waste gases and either burned (as fuel in the refinery) or simply allowed to

escape out the top of fractionating towers. These gases are now exposed to high pressure, heat and catalysts. This forces the molecules to unite and form liquids called polymers. Polymers are the essential components of high octane motor and aviation fuels."

Another key process for creating large molecules from smaller ones is alkylation. Alkylation makes high-octane molecules particularly well suited for blending motor and aviation gasolines.

"The American Petroleum Institute (API) estimates that without conversion refining, an additional 3.5 billion barrels of crude oil per year would be needed to meet today's (March 1980) gasoline requirements. Put another way, conversion has enabled refiners to produce over 20 gallons of gasoline from a barrel of oil vs. only about 11 gallons if no conversion process were in use."[6-1] (A barrel contains 42 gallons of crude oil; the precedent was set when Drake first shipped his crude out of Titusville, Pennsylvania in 1859, using 42-gallon barrels).

Cracking and polymerization can yield more of a desired product from a barrel of crude, but they lead to direct conflicts between products and customers. If the market demands more gasoline, heavier fractions can be cracked to increase the gasoline yield. This leaves less for diesel and jet fuel, which compete for the same fractions.

Literally, it should be possible to produce any product from any hydrocarbon source, if cost were no object. Asphalt could be dug from the street and cracked into gasoline. Some refinery coker processes are not too far removed. But the process costs are higher than for fractional distillation and either a large source of excess hydrogen is needed to fill in the smaller molecules, or fantastic quantities of asphalt would be used to extract the small amount of hydrogen it contains.

The product slate of a refinery, the prices of its products, its customers' demands, the refinery's processing capabilities and costs, and the type of crude it uses for feedstock, are all inexorably tied closely together, although individual customers may not participate in the decisions.

Aviation Jet Fuel

There are two major classifications of commercial jet fuel: The first, Jet A, is essentially 100% kerosene and, until recently, was only made and used in the United States. In Canada and other world areas, Jet A is beginning to replace Jet B. Australia has now made Jet A mandatory in its commercial operations. Jet A has a freeze point of −40°C. Its high-altitude version, Jet A-1, has a freeze point of −50°C.

The second fuel, Jet B, is a wide cut or gasoline/naphtha derivative, about 75% naphtha and 25% kerosene, and is the most prevalent commercial jet fuel used outside the United States.

In addition, the military JP series has been defined as different fuels were needed for various missions. JP-4 is the most widely used, essentially equivalent to Jet B and therefore having characteristics close to gasoline. Military operations include cold soak and starts in arctic climates, longer flights at higher altitudes, and greater requirements for altitude re-starts. JP-8 is essentially Jet A-1 and is now the NATO standard in England. JP-5 is close to Jet A and is used aboard aircraft carriers to minimize below-deck and combat hazards. Jet A, Jet A-1 and JP-5 are basically kerosene and are often called kerojet fuels.

"Kerojet is produced through straight run distillation. Several additional processes must be applied, however, in order to meet federal standards for safety and emissions control." These processes include sweetening (removing or converting malodorous mercaptans) of the fuel, desulfurization by hydrogen treating, caustic washing to remove organic acids or hydrogen sulfide and final cleansing in water wash and clay tower. These additional processes are not peculiar to aviation fuels.

Straight-run jet fuel is generally cheaper to produce than gasoline. It is almost identical to the lamp oil that oil companies produced in the pre-automotive era. At that time there was no ready market for the smaller gasoline fraction and it was often dumped into local streams. Tales of the Chicago River catching fire may not have all been legendary.

Most kerojet fuel is produced by the major oil companies. In fact, according to the Department of Energy (DOE), only 14 oil companies throughout the country are responsible for the production of 97 percent of all jet fuel.[6-1] That is, out of about three hundred refineries in the U.S., about 20 refineries provide most of the jet fuel production.

Jet Fuel Specifications

Stimulated by fuel shortages and the sharp price rises in both 1973-74 and 1979-80, refiners have become interested in the possibility of broadening jet fuel specifications. The feeling is that broader specs should make available a larger yield of jet fuel from a given barrel of crude at the same price, or the cost of producing an equal amount of fuel should be less. Perhaps both benefits could be realized at the same time.

In times of crude-oil supply disruptions, this broadened flexibility might permit refiners to deliver batches of middle-distillate fuels which would not comply in all respects with existing specs. Or refiners may be able to produce jet fuel from inferior grades of crude oil which could not be produced into jet fuel practically or economically under existing specs.

There are several qualities specified for jet fuel which may effect availability and cost. Its primary characteristics, however, define the upper limit for light components of the mix and the lower limit for the heavier components. Since extension of the light end or of the heavy end requires relaxation in opposite directions, their effects on aircraft operations and their effects on market conditions are considerably different. The light end and the heavy end will therefore be discussed entirely separately and should be considered in that light. The fact that broadening the spec on one end might appear favorable or unfavorable should essentially have no effect on whether broadening the other end of the spec should be considered favorably or unfavorably.

One additional component will be discussed, the percentage of aromatics in the fuel. Although not a direct function of the lower limit on the heavy components, aromatics and heavy fuel characteristics have similar effects on aircraft operation. Heavier fuels and more aromatic fuels contain less hydrogen. The question of aromatic content will therefore be discussed along with that of lowering the heavy end of the Jet A specs.

Fuel characteristics are not specified by the federal government. For commercial aircraft purposes, theoretically the manufacturer of a new engine may select any fuel or combination of fuels for which he wishes to qualify his engine. He then applies for engine certification with that fuel or fuels and substantiates, including demonstration, that his engine will perform safely and deliver the specified power under the conditions he also has selected. Any airframe manufacturer may then install that engine and operate it in his aircraft according to the specs set by the engine manufacturer

More practically, an engine manufacturer advises that he does not independently select a fuel spec. The airframe maufacturer selects his engine from a study of the aircraft sales market. Or,

for a combination of both a new airframe and a new engine, the engine and airframe manufacturers will probably jointly select the fuel. Once a type of fuel is commonly available, such as Jet A or Jet B, it is virtually automatic that new engines and new airframes will select one of those fuels for certification. Since commercial programs need to sell both to U.S. and to foreign airlines while many aircraft operate in both fuel areas, this means that aircraft manufactured in the U.S. (and presumably most of those manufactured in the rest of the Free World) are licensed to operate on both Jet A and Jet B.

If a special situation arises where an aircraft operator wants to use a fuel different than those specified in his aircraft's certificate, he must either apply for and demonstrate compliance for a new certificate himself, prevail on his aircraft's manufacturer to obtain the certificate for him, or persuade the engine manufacturer to go through the process.

All of these avenues have been followed. The process is rather simple for experimental aircraft, but becomes more comprehensive for commercial aircraft, where safety of the public is at issue. Specifications for the fuels themselves and for their various characteristics are usually defined by the American Society of Testing Materials (ASTM) for all segments of the industry.

It may be important to note that in principle, the conditions under which aircraft and equipment are granted commercial certificates are the ***minimum*** levels of safety and performance for that equipment. Airlines are encouraged to adopt operating procedures which exceed those minimums. In many cases, airline-established operating procedures are considerably more conservative and safe than the regulations or certificates permit.

Jet Fuel Flash Point

In other parts of the world which have had a lower population of automobiles, naphtha has been a surplus product and Jet B became the popular jet fuel available outside the U.S. American carriers operating abroad have naturally become accustomed to using Jet B. The specification for Jet B does not include a flash point requirement. On average, the flash point of Jet B, as delivered, is usually around 0°F or below.

As has been indicated, gasoline has been a premium product in the U.S. refining market and U.S. airlines have characteristically operated their turbine engines on Jet A. Jet B is typically not available in the U.S., the naphtha being used for gasoline. Jet A has a low vapor pressure and a flash point specified not to fall below 100°F.

Curiously, most Jet A delivered in the U.S. has a flash point of 125-135°F. The reason lies outside of aviation. Jet A specs are so close to heating oil that refineries often turn out a single product which qualifies for distribution to both customers. Boiler operators and owners of home furnaces do not employ the same safety conditions, procedures, and equipment as aviation operators. Therefore, in most states and local jurisdictions within the United States, oil used for boilers and home heating may have a flash point no lower than 120°F. When jet fuel is made in a batch that will also go to heating oil customers, ***or when it will be delivered to airline customers through heating-oil channels***, it must typically meet the local flash-point specifications.

Refiners' discussions in aviation meetings have not been specific that a relaxation of Jet A flash point below the 100°F level would actually improve their cost and quantity situation. The FAA had planned and had started a series of subcontracted tests to determine safety characteristics of jet fuels with flash points below 100°F. Budgetary pressure has now deferred these tests. It appears doubtful that these tests should be completed unless refiners expect to produce and distribute jet fuel separate from heating oil, or to obtain waivers for jet fuel distribution through the heating-oil distribution channels.

Under most conditions, Jet A cannot be ignited readily with a match. In tests which involve burning Jet A, a large blow torch is used to start the combustion and, due to the lean vapor above the liquid, the flame propagates slowly. It's like the backyard charcoal lighters which are pesky, but safe.

As has been noted, Jet B is made from naphtha components and is much like gasoline. Like gasoline, it would not be suitable for lighting a charcoal fire. The accident record of Jet A vs. Jet B has been examined by the Coordinating Research Council.[6-9] Although the safety record with both fuels has been good, there is significant difference in crash-fire survivability favoring Jet A. On the other hand, gasoline is used daily in thousands of aircraft and millions of automobiles with reasonable safety. Problems that are encountered are generally due to fuel misuse, a failure to follow fueling recommendations, or to appreciate the extreme danger of combustible vapors near an ignition source.

The practical difference with fuel volatility is during handling and fueling. Most experience with fires has been with aircraft fueling, defueling or maintenance operations. Jet B fires generally resulted in destruction of the aircraft, while Jet A fires produced only moderate damage. Fueling poses the unique hazard of generating and accumulating electrostatic charge unless the fuel contains an additive to increase its electrical conductivity. A spark discharge from a body of charged fuel can ignite Jet A or Jet B mists. Bonding the aircraft to the ground servicer is essential during fueling and prevents an external spark discharge when hoses are connected. Grounding the aircraft either directly or through the bonding system of the grounded servicer is also essential to allow charges generated during fueling from either servicer or aircraft to flow to (or from) the ground.[6-9]

An ignition may not be as catastrophic as one might imagine. The propagation of a flame front through mists proceeds more slowly and produces a lower pressure pulse than the rapid explosion of Jet B vapors. In several cases of Jet A mist ignition cited in the CRC report,[6-9] structural damage to the aircraft was extensive but repairable. By contrast, most of the ignitions of Jet B vapor resulted in wing tank explosion, extensive fire and aircraft destruction.

When an aircraft crashes at speeds corresponding to takeoff or landing, the type of fuel in the aircraft has not been found very significant. On impact at those speeds, the forces are high enough to rupture fuel tanks and blast fuel liberally over the area. Droplets are small as in a mist and the likelihood of sparks is so great that the fuel usually goes up in a fireball, whether gasoline, Jet B, or Jet A.

There has been considerable research, with some promise of success, toward developing an anti-misting agent for mixing with Jet A. When Jet A is prevented from misting in a crash, tests show it is much more benign. It is doubtful that the more volatile Jet B could ever be made anti-misting. Although the possibility of an anti-misting Jet A has been promising for many years, it must be acknowledged that success has been very elusive and it may never be successful.

This is not the entire story, either. Aircraft fueled with Jet B have run into obstacles at low speeds and have caught fire where it is thought Jet A would not have ignited. A trail of spilled Jet A is not likely to lead a flame to a damaged aircraft, as it is with Jet B. With its low vapor pressure, Jet A vapor is unlikely to be sucked into a still-running engine's intake, to be ignited. Passengers have literally waded away from wreckage through spilled Jet A. Few contend that it would have been possible through Jet B.

Aircraft are seldom struck by lightning in flight. Their structure and fuel systems are electrically bonded internally to prevent sparking and are generally regarded as safe against lightning strikes. But lightning in many ways is unpredictable and at least one aircraft has been lost which might have been been due to a combination of Jet B and lightning. It can only be conjectured if the airplane would have been lost under the same conditions if it had been fueled with Jet A.

Otherwise, the practical difference with fuel volatility is during handling and fueling. Since the operating safety record with all fuels has been relatively good, most experience with fires has been from research and development operations. Those most experienced comment that even Jet A handling can be a problem under hot, desert conditions. So the solution, the real safety, should be achieved through care of handling, assurance of a good electrical ground during fueling, an anti-static additive in the fuel, and good integrity of the electrical bonding system within the airplane, both in its original design and as maintained throughout the aircraft life.[6-6]

The FAA specifies more careful fueling operations with the more volatile fuels but, once the fuel is in the airplane, the pilot is not greatly concerned with any difference. In fact, there are some aircraft turbine engines which are certificated to run on gasoline or a mixture of kerosene and gasoline. This is not recommended standard practice and special care is taken with grounding the aircraft during fueling, to prevent sparks from static electricity. Generally, gasoline would be loaded in U.S. jet aircraft only in "emergency," when kerojet fuel is unavailable.

There are both pros and cons toward lowering the specification flash point of Jet A below 100°F. For example, Canadian airlines have used fuel with a flash point of 92°F, which they unofficially call Jet A-2. U.S. people object associating the Jet A label with any fuel which has a flash point lower than 100°F (some in the U.S. prefer to call it Canadian jet). But, since the Canadians do not share our southwest desert temperatures, while they often must leave their aircraft out overnight in subzero weather, their spec needs are clearly different from ours.

Jet A volatility is so low that its tank vapor is lean and almost always unignitable (except, perhaps, after sitting for a long time in the sun). On the other hand, like gasoline, the vapor in the tank above Jet B is too rich to ignite. Only a small amount of Jet B in a Jet A/Jet B mix should vaporize sufficiently to produce an over-rich vapor space. The question must be asked, then, what ranges of mixes, temperatures, pressures, humidities, etc. may be hazardous and what strengths of sparks will ignite them? Is there a significant range of hazardous combinations in those possible? There are some opinions, but little substantive evidence.

The question probably resolves to whether, in the case of another severe disruption in crude supply, if either Jet B or JP-4, its military equivalent, is available, should U.S. airlines use them and mix them with the Jet A they still have aboard? The answer is probably, "Yes." There is certainly no regulatory prohibition. But it would be important to use a conductive additive in the fuel. If normal care is exercised during the fueling process and grounding is secure, there may be no additional sensible risk. The next question would be, "Should the practice continue if the crude disruption continues and the situation presents itself often or continuously?"

The answer there could well be, "No." Because, over extended time, accidents then would be more likely to occur in which Jet B would represent a more probable risk than Jet A. It may be like the difference in risk between diesel and gasoline-powered automobiles. There is probably a real difference in risk, but nobody makes a big affair about it. If we had started with diesels and the question now was whether to introduce gasoline, gasoline cars might be strongly resisted. In most accidents it makes no difference, but there are exceptions. Australia's mandate for Jet A is probably supported by logic.

Lowering the fuel's flash point creates no problem with aircraft or engine operation or performance. If anything, starting and running should be improved. The combustion should be a little more complete, radiant heat a little more gentle on internal components, emissions should be reduced slightly, and so forth. But the effects would probably be too slight to notice appreciably. The only question with extending jet fuel to lighter fractions is that of safety, and that is presently, at least, still a moot question.

Jet Fuel Freeze Point

If jet fuel specifications are broadened to include heavier fractions, the immediate effect would be to raise the freeze point of the fuel. Freeze point may be significant with aircraft when they fly at altitude long enough to chill the fuel. These conditions are not encountered frequently with present fuel and Jet A-1 was introduced largely for over-the-pole flights. But, if a jet airplane is forced to fly at lower altitude to find higher temperatures, the penalty in performance and fuel consumption will usually be appreciable to severe.

Jet fuel does not initially freeze hard like water. First it becomes cloudy, but is completely pumpable. Then it begins to form wax in small particles or crystals, which build into a network or matrix. These particles may agglomerate and clog filters. Once wax begins to form in the fuel, it proceeds rapidly with further small decreases in temperature. It may form viscous or rope-like strata that progressively degrade fuel pump performance and clog engine spray nozzles. When fuel freezing occurs, it presents problems in both the aircraft fuel system and in its engine parts.

Boost pumps in the aircraft tanks introduce heat which delays the process and, in most situations, the fuel could probably be used in outside temperatures several degrees below its freeze point. Further, all commercial aircraft use fuel heaters below specified temperatures to prevent freezing of water in the systems. Also, cruising at high speed, even at high altitude, adds aerodynamic heating to the aircraft skin. But, as temperature within the fuel itself decreases, the freezing symptoms will be encountered.

Jet A freeze point is specified to be no lower than −40°C, which is also −40°F. Since standard temperature at 35,000 ft. altitude is −65°F, the Jet A spec does not protect aircraft from all conceivable regimes of operation. An airplane flying for long ranges at high altitudes, such as a Boeing 747SP nonstop from New York to Tokyo, may expect its fuel to chill down below the Jet A freeze point. Military aircraft, which may generally perform high altitude missions for long periods of time, therefore use their JP fuels instead of Jet A.

If commercial aircraft expect to fly for long ranges or times at low temperature, they may fuel up with Jet A-1, which carries a freeze point of −50°C. As a matter of interest, the Canadian jet spec (which they call Jet A-2) has a flash point of 92°F as compared to 100°F, as already noted. But it also provides a freeze point of −45°C from April through October and a −48°C freeze point during the rest of the year. So the Canadians adjust their standard fuel range to lower temperatures on both ends.

Aircraft fueled with Jet A may be required to reduce their cruise altitude according to the outside temperature and the time for the flight. Generally, this is not required for Jet A on

any routes within the United States. About 1% of the over-the-pole flights encounter temperatures which require them to reduce altitude. With the proposed increase in freeze point, it has been speculated that flight diversions could occur in 5% to 30% of those flights. Conditions are specified in the airplane's operating manual and they include a margin of safety for headwinds, holding time, and other contingencies.

But it is uneconomical in fuel consumption to fly a jet airplane at an altitude different from optimum. This is particularly inefficient at altitudes lower than would be selected. For a Boeing 727 flying at 30,000 ft., a diversion to 25,000 ft. to increase temperature 10°C increases the cruise fuel burned by 13%. As will be seen in Chapter 11, airlines are marginally profitable on fractional percentages of fuel consumption; a 13% penalty is a serious economic sacrifice.

New aircraft such as the Boeing 757 and 767 reject less heat to their fuel (they have better internal heat conservation), fly at 5-10,000 feet higher altitudes, and would expect to suffer greater fuel consumption penalties if required to lower their cruise altitudes. The penalty is greater for smaller aircraft such as business jets, which have smaller fuel tanks, with a greater surface-to-volume ratio.

So there is resistance to the suggestion that the freeze point of fuel might be raised. With a higher freeze point, aircraft would doubtless have to divert to lower cruising altitudes more often.

One alternative would be to modify aircraft fuel systems and engines, to improve insulation, or to provide artificial heating at the appropriate points. But modifications are themselves expensive and may be heavy. If the main tanks must be insulated, the tank fuel volume would probably be decreased. Unfortunately, it is the long-range, high-altitude flights which both need maximum fuel capacity and are most susceptible to the freeze-point problem in the first place.

Should the industry consider varying the specs with time of year or for various classes of missions? This solution could cause more price and distribution problems than the present Jet A spec.

Fuel system freezing is not the only problem introduced by raising the spec freeze point. In heavier fuel fractions, the ratio of hydrogen to carbon is lower. The heavier fuel will not ignite as easily, burn as cleanly, or produce as much energy per pound of fuel. Perhaps more significant, a heavier fuel burns with a more luminous flame, projecting more radiant heat. This is a critical situation inside the engine. Particularly in the engine burner section and in the turbine section immediately downstream. Engine stresses and the maintenance life of engine parts are dependent on the radiant heat these parts receive from fuel combustion. U.S. Air Force (USAF) tests have shown that engine turbine life increases 50-100% as the fuel hydrogen content is increased from 13 to 15%.[6-4] Jet fuel typically has a hydrogen content of about 13.7%.[6-5]

It has been suggested that these engine parts could be redesigned to accept more radiant heat and that existing engines could be modified. That could be done. But the costs would be considerable. Unfortunately, too, going to a fuel with more luminosity is going opposite to the direction that improvements have followed throughout the history of jet engine development. For increased performance, reduced weight, less maintenance and longer engine life, most of the expensive effort in jet engine development has been directed toward improving these "hot section" parts. Turbine blades and rotors are the most expensive parts in the engine.

These parts have been designed with the most advanced technology. Turbine blades have been developed using single crystals of metal in order to achieve the highest strength for their weight and space. Both stationary and rotating blades are cooled with air in internal passages. This air comes from the engine compressor, where any air robbed after compression represents leveraged degradation in engine performance. Although highly undesirable in both cost and national security, exotic materials are used in engine internal metallurgy to squeeze the utmost in weight, space and fuel economy.

Most engine design attention in the past has been toward performance (thrust and weight) and maintenance, rather than fuel consumption. Ironically, now that fuel consumption is assuming the dominant role in airline operation due to high fuel prices, it is parti[illegible]ly undesirable to consider a change in fuel specs which wou[illegible]grade performance and fuel consumption.

One might say [illegible]at relaxing the jet fuel spec toward heavier fractions is effectively reversing the high technology achieved in a generation of engine development. A heavier jet fuel might be cheaper. But it would also be cheaper to use cast iron in engine parts. The reason exotic metals and design techniques are used is that they pay off in aircraft and engine economics. It would make sense to degrade jet fuel only if a lower fuel price can pay for the attendant losses in aircraft and engine economy.

Philosophically, it is generally cheaper to solve special problems on the ground than in an aircraft. Aircraft and engine designers should be hoping for higher-grade fuels, rather than designing and testing to accept lower grades.

There are other reasons why raising the jet fuel freeze point would be disadvantageous. A new aircraft engine design usually takes around eight years to develop, longer than a new aircraft model. The reason is that the engine must be tested much more extensively, since so much of its economic success depends on the engine's maintenance and life characteristics. Much of this testing must be in real time at real performance conditions. So, if a reduction in fuel price is going to pay for developing the new engines which can use a newly specified fuel, the fuel price advantage must prevail for many years.

In fact, the eight years of engine development are only the start. Engines and the new aircraft (or, at least, new aircraft fuel systems) must be able to realize that advantage in fuel price over the life of the equipment. Amortization life is usually taken as twenty years.

So far, refiners are only conjecturing about lower prices for heavier fuels. The trend sounds reasonable as crude oils become progressively heavier around the world; everyone agrees that crudes are and will be getting heavier. But no refiner has yet offered how much the cost of jet fuel could be reduced for any given relaxation in specifications. The fact is that the effect on cost will likely vary from refiner to refiner and from crude to crude, probably from time to time.

Further, a reduction in cost may not necessarily bring about a corresponding reduction in price. Each refinery must operate at a profit. Depending on market demand and the characteristics of the crude available, and of course dependent on the capabilities of the refinery itself, a refinery may not be able to sell all its products at equal profit margins. Some products, such as residual oil, may be sold at a loss. This loss is offset by higher prices of other products and it can vary considerably from time to time. It may be unreasonable to expect refiners to agree on firm price policies for jet fuel, much less guarantee them with enough certainty to either modify existing aircraft and engines or to develop, build and certificate new equipment.

At the Georgetown CSIS discussion of this project, Dr. Maurice E. Shank, Director, Engineering-Technical, Pratt and Whitney Aircraft Group of United Technology Corp. and Albert M. Momenthy, Manager, Transport Energy Systems, Boeing Commercial Airplane Company, made it very clear that they

consider the decision on jet fuel specifications effectively has already been made past the year 2000. Dr. Shank remarked that Pratt and Whitney has spent about $100 million to reduce emissions in present engine technology and that a heavier fuel would jeopardize that investment. Present combustion efficiency in aircraft engines is over 99% at high power settings; a heavier fuel would necessarily reduce this efficiency, with increase in emissions.

New combustors to accept heavier fuels would cost $100 million to develop and produce. Modified turbines would be even more expensive. The cost of developing a new engine is around $1 billion, about the net worth of the company. The new generation of aircraft (B-757 and 767) yet to be delivered and, indeed, any now on the drawing board, are all predicated on Jet A (and Jet B).

The final solution may lie with the refiners themselves. Most major companies are already rebuilding old refineries or constructing completely new plants with extensive capabilities in coking or hydrogenation to reduce their output of residual oil and increase their slate of lighter products. While these plants are being amortized, it may be expected that product costs will be somewhat higher than for straight distillates. But, as plants and processes mature and, particularly with development of cheaper and improved catalysts, there is strong promise to produce quality fuels at standard costs.

Indeed, the field of catalysis appears to offer some of the most promising possibilities in the entire energy and fuels processing picture. There appears to be good hope for super-fuels (higher hydrogen content) at standard prices within five to ten years.

At the CSIS forum of October 1981,[1-2] S.V.Drum, General Manager, Aviation, Chevron, remarked, "We receive endless questions of whether broadened jet specifications would result in increased availability and decreased price. We may differ from some of the other views you will hear here, but it is our conclusion that broadening the specifications within the mid-distillate range will not necessarily result in a substantial increase in the supply. When supplies of distillate are long, as they are today, no one is having any problem getting the jet fuel they need. When times are tight, aviation will get about its share, along with the diesel customers and the 2-oil customers. If we broaden the specs for jet fuel, we would reduce the production of the components for these other customers, for which there is an increasing demand."

"One change that could increase availability would be a relaxation in flash point, due to the decreasing demand for motor gasoline. In times of plenty, this could have an impact (downward) on price. When the industry is long on alkylate, the price of JP-4 (Jet B) has reflected that. Also when alkylate has been tight. I believe the same would hold in going to a lighter-product jet fuel, encompassing some of the gasoline which is now going to become surplus. It ***could*** have an influence on price in times of plenty."

Also at the CSIS meeting, the petroleum market was concluded to be probably more unfavorable than favorable toward a heavier jet fuel. It was pointed out that demand for automotive gasoline has been on the decline and is projected to decline further. In contrast, the demand for diesel fuels and other middle-distillates is generally assumed to be increasing, with prospects for higher rate of increase in the future. These other customers will be stiff competitors to aviation for middle-distillate components. They command a much larger proportion of the market.

Further competition in the middle-distillate market might be quite adverse for longer-term aviation fuel prices. In the longer run, aviation may be in a better market slot with Jet A than with a heavier fuel.

So this report concludes that the likelihood of aviation accepting a heavier jet fuel specification is very slight. Even so, refiners may not recognize the difficulties presented by a heavier fuel and may hold out hopes that some degradation can be accepted in the near-term future. The National Academy of Sciences/National Research Council has held a series of meetings at which the principals have discussed the possibility for widening Jet A specs. It is hoped that their report will be conclusive and that it will be distributed widely enough to influence future planning.

Otherwise, it might be worthwhile for the aviation industry to organize a discussion with the refining industry so that misunderstandings do not build further. Planning for new refinery capabilities and new aircraft/engine fuel acceptance should not be permitted to drift down disparate paths.

Aromatics

As contrasted with the straight-chain molecules of paraffinic hydrocarbons, aromatics are isomers with ring-like structures. With more complex bonding, an immediate comparison shows that aromatic molecules contain fewer hydrogen atoms per unit weight. So aromatics present some of the same tendencies of heavier hydrocarbons. They produce less energy per pound, they tend to coke, they burn with a more luminous flame, and they generally produce more emissions. Consequently, many of the comments above directed toward the use of heavier fuels in aviation, also apply to fuels with heavier aromatic content.

Aromatics attack many elastomers and sealants and that was the original reason for limiting their content in fuel. Now the more radiant flame from aromatics, and its effect on engine hot parts, is of equal concern to operators.

Aromatic content is usually limited by purchase agreement between the aviation customer and his refinery supplier. Aromatics are permitted up to 20% and are accepted up to 25%, with the supplier advising the customer of deliveries made above the 20% level. This notification permits the aviation operator to make more frequent inspections to determine if the increased aromatic content is deteriorating his equipment.

The relationship between aromatics and other components, with hydrogen content and the combustion energy of fuels, is shown in Figure 6-2. There is a direct ratio between the hydrogen content in the fuel and its heat of combustion per unit weight. It is important to note that this relationship is ***per unit weight***. Since hydrogen occupies more volume than the corresponding weight of carbon, when hydrogen content increases, ***the energy per unit volume decreases***.

For most aircraft flights, it is the weight which is important and a higher energy per pound is desirable. But, if the tanks are filled full for maximum range or endurance, if fuel tank ***volume*** is the limiting factor, then more energy per gallon is desirable. Further, fuel is priced by the gallon, not by the pound. So fuel producers point out that a high-hydrogen fuel or the super-hydrogenated fuels mentioned as possible above, may not be so attractive in price-per-pound, or for long-range operations.

Jet aviation has either been extremely lucky or guided by intelligent decisions at the outset . . . probably some of each. Kerosene turns out to have good handling characteristics, while it rates favorably in cost/energy, energy/weight and in energy/volume. It is probably the best aviation turbine fuel that could have been selected. Some space-oriented projects have used jet fuel along with liquid oxygen or other special oxidizers. Unless the price should become too high, it would be attractive to pack

more hydrogen into the fuel. This is one of the paths leading to interest in hydrogen as a primary fuel in aviation. Hydrogen proponents say, "Why not go all the way at one step?"

A current trend and further expectation toward increasing aromatics in crude oils leads to natural consideration of higher aromatics for aviation fuel. Aromatics are not synonymous with heavier fuels. Aromatic fuels have very good anti-knock characteristics and they are valued in gasoline production for that quality. But anti-knock tolerance plays no part in turbine operation. The pressure for more aromatics in jet fuel may come more from decreased automotive gasoline production than from the changing quality of crude oils. Cutting down mogas production will leave the refiners with more aromatics to dispose of.

This whole question of crude oil content, refining capability, and product slate demanded by the market, is in a period of rapid transition. It does not appear that aviation and refining industries should agree to raise the freeze point or the aromatic content for standard jet fuel specs. On the other hand, it would be prudent for aviation to determine how much degredation in jet fuel specs could be tolerated for more-or-less temporary interruptions in normal crude-oil supplies.

NASA should approach this question of fuel tolerance, not on the basis of significant modification or development in new engines or fuel systems required to accept a broader-spec fuel as standard, but to investigate the effect of various fuel degradations over various periods of service time. This information would assist the aviation user to assess the consequences of using any sub-grade fuel he is offered during an emergency or at a low price. It would also assist the refiner to know where he may be able to market an off-standard fuel during an emergency, or whether he should process it in his plant to a more marketable standard.

It may be worthwhile mentioning one more consideration before leaving the subject of jet fuel specifications. As will be seen in Chapter 8, there are many reasons to believe that shale oil will replace petroleum as the source for jet fuel, sooner or later. Shale oil has problems, which are discussed in the chapter. But, as its production and processing are planned and have been tested, it produces a large proportion of high-quality jet fuel per barrel of shale crude. This fuel is well within existing jet fuel specifications and is very low in aromatic content. Because of this low aromatic level, it is much better suited as a source for jet fuel than for gasoline.

Shale oil may be the next large step down our fuel transition path. Since it conforms better to existing specs than fuel produced from our present refinery feedstocks, this would seem to be an unfortunate point at which to accept the penalties associated with heavier fuels or higher aromatic content.

Aviation Gasoline

There are a number of problems associated with aviation gasoline; the most prominent are price and availability. Ironically, aviation gasoline basically is cheaper to manufacture than lead-free automobile gas. Even low-lead aviation fuel contains more lead than standard auto gas. The main problem is that aviation gas is produced in about a half-dozen major refineries in the United States and that it is run on a batch process.

Typically, a refinery may take three days in converting over to avgas production. Then, in five days or so, it produces a five-month's supply of avgas. In itself, this presents some storage and

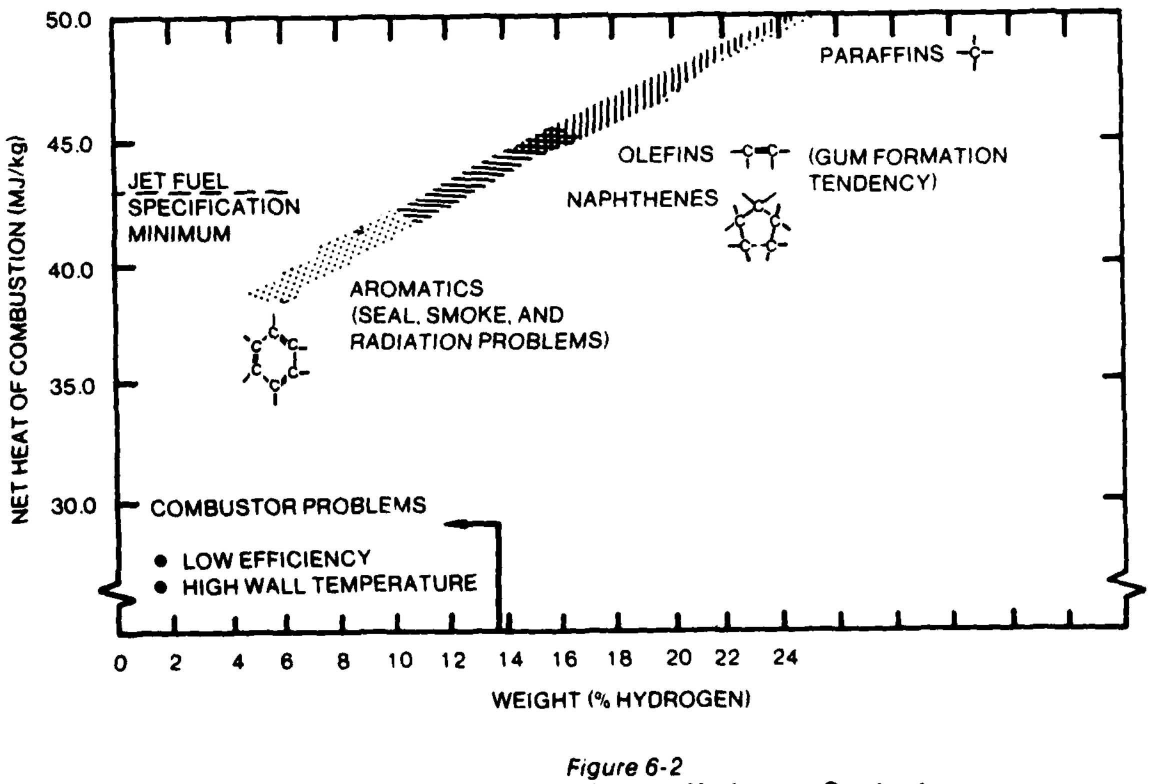


Figure 6-2

Fuel Property Sensitivity to Hydrogen Content Hydrocarbons

handling problems. But it then takes about a week more to reconvert the refinery back to its normal operation. So avgas has to bear the cost of two revisions in setup, its own production time, and lost refinery time.

Distribution adds to avgas problems. Its final destination includes 500 small airports around the U.S. Most petroleum products are transported by pipeline. Here avgas suffers in two respects. Pipelines typically transport about 45,000 barrels per hour. The whole nation's daily avgas consumption is only about 40,000 barrels.[6,7] Pipelines ship a variety of fluids and, if adjacent fuels are compatible, there may be no degradation of the fuels in the market. Avgas cannot share this treatment. As a result, avgas is transported largely by barge and truck.

The primary consideration and concern with avgas is flight safety. Its specs are correspondingly well defined, in general, much more tightly defined than for other products. If avgas becomes "contaminated" with another product, the qualities of that product may not be well known. Because avgas is held to such well-defined specs and because its qualities can be deteriorated without careful handling, avgas is usually checked as it leaves the refinery and then treated like a sterile surgical instrument.

If it is piped through a line, held in a tank, shipped in a truck or barge, pumped, or exposed to environment or materials which could contaminate it or degrade its quality, it may lose its certification as avgas. Recertification of a batch suspected of contamination means shipping a sample back to the refinery. Generally, only the refinery has the capability for making the tests necessary, as well as the expertise to determine whether the fuel is still usable in aircraft and, if not, what to do about it.

U.S. gasoline-powered aircraft shared at least the same problems with other fuel customers during the 1973-74 OPEC embargo and the 1979-80 Iranian revolution and Iraqi war. They suffered another shock when the Phillips Petroleum refinery in Borger, Texas experienced explosion damage in 1981. At one stroke, 6,000 b/d of the US 40,000 b/d production capability was interrupted for many months. Aircraft operators in the entire southwestern U.S. were affected immediately and the ripples were felt through probably most of U.S. avgas circles. This explosion emphasized how dependent the gasoline-powered aviation industry is on a small group of refiners and on limited distribution channels.

The international avgas market, at present, is in a tighter situation than within the U.S. The former British Petroleum refinery in Abadan, Iran produced about a third of the Free World's supply of avgas. Since that supply has been interrupted by the Iran-Iraq war, almost a hemisphere of the globe has suffered from avgas supply and distribution shortages. Since the U.S. manufactures the majority of the world's general aviation aircraft, this international avgas supply problem is a major concern to our small aircraft producers.

If the market and distribution problems were not enough, avgas compounds the problem by being produced in three grades: 80 octane, 100 octane and 100 octane low-lead (100LL). The reasons go back before World War II, when most aircraft engines used 92 octane or lower. But the war demanded highest performance; the Spitfires and Hurricanes developed their performance superiority only after they were supplied with 100 octane gasoline.[6,8]

After the war, an effort was made to standardize on a single grade, 100 octane. But 100 octane used more tetra-ethyl lead (TEL) and the military engines had been built with a much higher tolerance for lead. Lead fouls spark plugs and causes other problems in small engines.

100LL was proposed as the solution; it would provide the octane that the big engines required and reduce the lead unfavorable to the small engines. It was then found that some of these high-strung, powerful engines really depended on lead for valve lubrication and other functions. And, before that situation was solved with enough assurance, a new generation of engines had evolved that ***required*** the octane and the low-lead qualities of 100LL. Ergo, three grades of aviation gasoline.

The situation is certainly fraught with problems. Engines requiring lead may be modified or the 100LL may be revised to provide the characteristics they need. The smaller engines can operate on 100LL, but with more frequent inspections and maintenance. Another avenue being analyzed is the possibility of using autogas, or mogas, in the small aviation engines which do not require 100 octane.

Mogas Substitution in Aircraft

It is not legally permissable to use mogas in aircraft engines because those engines have not been certificated for mogas. In England, the possibility is being given serious consideration and appears to be nearing approval. But the British Isles represent a different situation than the United States. The U.S. covers a vastly greater range of climates and altitudes.

U.S. mogas is produced to different specifications in seventeen regions of this country, each blended for best performance in its distribution area. These blends are changed four times a year with the seasons. A car carrying a tank of gas into another area is unlikely to encounter problems because it rarely if ever develops full horsepower. Even so, there are problems in taking unsuitable gas into the mountains, while vapor lock may be encountered in desert areas.

But an aircraft engine generally uses full power on every takeoff. Full power is particularly important at airports above sealevel. Aircraft safety is dependent both on power output and reliability. At present, there are three essential problems with using mogas in U.S. aircraft: 1. The variety of U.S. mogas blends, 2. Mogas characteristics are not as well defined, controlled or known at the refinery, 3. Mogas handling permits more contamination.

The situation may not be impossible. Refineries are now able to produce high-grade, lead-free gasoline as a standard product. With the decrease in demand for mogas and further decrease forecasted, some refiners may find more interest in the aviation market and a further outlet for their gasoline fractions.

Advocates of less expensive motor gasoline suggest that refiners manufacture batches of mogas for which the vapor pressure, octane level and other major characteristics are suitable for aircraft operating on 80 octane avgas. These batches of gasoline could be marketed as auto/aviation fuel, usable interchangeably in either. Aviation fuel suppliers would be able to buy it as avgas and, through their normal distribution, would be able to assure its integrity. Refiners are skeptical that the price would be lower, while they point out it could satisfy only the smaller engines which use Grade 80 gasoline. Another consideration is that most of the smaller gasoline engines which are being manufactured now can tolerate 100LL.

It is general knowledge that some private pilots in the U.S. today are using mogas in their aircraft. For those who know what they are doing, as well as the quality of the fuels they are using, the operation can be as safe as using avgas. Problems occur when the pilot is not knowledgeable, when the fuel characteristics are not really known, or when the fuel may have been inadvertantly or unknowingly degraded.

Flight tests are being run on a Cessna 150 powered by a Continental 0-200 engine toward certification with any autogas which meets ASTM D-439. It will be a Supplemental Type Certificate (STC) which will permit recreational flying only, not in aircraft operated for hire. Presumably, other equipment which uses 80-octane fuel can apply for similar certificates.

Whether a solution in Britain, the U.S. and other well-controlled areas can be translated into a world-wide solution for aviation fuel remains to be seen. In the meantime, U.S. general aviation manufacturers are interested in developing new engines with a wider tolerance for fuels. Some even hope to produce engines which can operate satisfactorily through a wide range of light fractions to heavier middle distillates.

This may be possible with turbine engines. The trick will be to develop an engine and fuel system which are self-adaptive to fuels and will not require modification or manual adjustment as different types of fuel are loaded. Through adaptive electronic fuel and engine controls, some believe it will be possible, though difficult, to develop systems which will permit a pilot to load virtually any fuel which happens to be available. He could then buy fuel with the highest available energy content per dollar and the engine/fuel system would adjust itself accordingly.

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Chapter 7

Natural Gas

Board Room Briefing No. 7

1. At the risk of appearing farfetched, this author concludes that development of natural gas in the United States offers the greatest potential for reducing fuel prices, stabilizing supply, reducing foreign oil imports, and accomplishing this in the shortest time, of any energy or fuel option available to this country. These achievements also probably would be made at the lowest cost for any major, single move in energy.

2. Natural gas has no current direct application in airline aviation, but can offer advantages to general aviation (see final two paragraphs of this chapter, plus Chapter 9). The greatest obstacle to natural gas is its present legislative restrictions. The 1981 Omnibus Budget Reconciliation Act (PL 97-35) has made important improvements. The Natural Gas Policy Act of 1978 provides for "deregulation" of natural gas and will remove additional restrictions in 1985. But the U.S. energy picture could be greatly improved before 1985 (without accelerated deregulation of gas prices) and afterward, softening the U.S. petroleum price picture and, in turn, the aviation fuel price/availability situation.

3. Increased use of natural gas would benefit aviation and the U.S. petroleum picture most by substituting for petroleum in stationary power plants and industrial applications. Coal and nuclear power are capable of similar substitution and should play important roles. But coal involves physical and environmental problems as well as institutional problems of its own. Nuclear power appears at least temporarily overcome by public opposition and the increased costs that are being demanded for safety. Nuclear powerplant construction requires much more capital and time; coal-powered powerplants are also more expensive, as are emission controls for burning coal. Natural gas is more versatile than either. The U.S. is denying itself the many advantages offered by natural gas.

4. Natural gas resources are more difficult to forecast than petroleum. However, virtually all forecasters either acknowledge or proclaim that natural gas resources far outrank oil and may be the world's largest source of fossil fuel. The U.S. gas resource is acknowledged to considerably exceed our oil resource and production should be easier. As compared to 30% production of oil and up to 50% by EOR, gas resources are normally 80-90% recovered. Legal and institutional constraints, rather than resources, limit present gas use and its future potential.

5. If available at prices and in quantities that a free market should generate, natural gas converted into methanol should back additional petroleum out of the stationary-powerplant market. Methanol should replace petroleum in some surface transportation markets over a period of time.

6. Compressed natural gas (CNG) and liquid natural gas (LNG) offer additional opportunities for surface transportation, with the cost of compression or liquefaction replacing the cost of conversion to methanol. Use of CNG and LNG will further release petroleum for air transportation.

7. With the large quantity and world availability that natural gas apparently promises, it is possible that methanol may become the world's major petrochemical feedstock. It is more than conceivable that natural gas and/or methanol will eventually replace petroleum fuels as the most available, cheapest portable fuels. Irrespective of U.S. action, the development of natural gas and methanol is likely to accelerate on a world scale. But natural gas appears to offer the U.S. more opportunities and benefits than for most nations.

8. As a chemically convenient source for hydrogen, natural gas development could be extremely useful in refining heavy crude oils and synthetic liquid fuels. This methane-derived hydrogen could also be used to upgrade or supergrade petroleum or synthetic fuels for aviation and other high-efficiency users.

9. In a free market for natural gas, hydrogen produced from natural gas could conceivably become a cheaper fuel per Btu than petroleum or synthetic fuels. A hydrogen-powered airplane would also burn fewer Btus per passenger-mile.

10. As liquid methane (LCH_4), natural gas becomes a cryogenic fuel approaching many of the desirable qualities of hydrogen. It is light, clean, energetic, and its combustion creates the least carbon dioxide of any hydrocarbon fuel. Its cryogenic potential for providing aircraft laminar flow control, with an additional potential fuel saving of up to 40% in cruise, would probably equal that of liquid hydrogen. To attain economic feasibility, supersonic transports probably will have to be powered with LCH_4 or LH_2.

(Items 9. & 10. are discussed in Chapter 9)

The Natural Gas Situation

The natural gas situation is unique but, in many respects, it is like the U.S. potential for enhanced oil recovery (EOR). It is limited far more by institutional barriers than by technology or economics. But natural gas offers several important advantages over EOR.

EOR is concerned with a resource already known to be in place and of sizeable quantity. But our ***proved*** reserves of natural gas about equal that EOR potential, in equivalent barrels of oil. (Our proved gas reserves, about 200Tcf [trillion cubic feet]

of gas, are equivalent to 34 billion barrels of oil; EOR potential is estimated at 18-50 billion barrels in Chapter 5, including EOR enhancement of ***new*** oil, yet to be found).

In addition to these ***proved*** gas resources, there is estimated to be up to more than 800Tcf (136 billion barrels, oil equivalent) of potential ***conventional*** domestic gas, and perhaps double that amount of unconventional gas. (The quantities are discussed further in this chapter). So the potential for natural gas energy appears to be up to 15 times as great as for EOR, and without many of the risks, high costs like the extra injection wells, and the long time investment required by EOR.

Where EOR is inhibited at the source primarily by taxes and also by regulations against its production, gas is restricted partially by price ceilings, but more by prohibition against its use. At present, natural gas sells (due to regulations) at an average price of about $2/MCF (thousand cubic feet, which is about equal to a million Btu). Also due to regulation, this price varies from less than fifty cents per MCF up to $9 per MCF.

Gas prices are so far from free-market conditions that most of the arguments today revolve around what the consequences would be of transitioning to a free market.

At $33/bbl, oil is selling at $5.70 per million Btu. So, while some gas is selling at prices higher than crude, other gas is sold at less than 10% of the marginal world price of oil. Easing the cost ceilings on low-price gas would bring some increase in production, but much more gas would be used in the U.S. if it were not prohibited by regulation.

Because of use restrictions, the present U.S. capacity for producing and supplying gas is greater than the current demand.

In Chapter 5, EOR was characterized as an orphan. Due to different interests, institutional problems and circumstances, natural gas also shapes up as an orphan when compared to conventional petroleum. Gas is traditionally an adjunct to petroleum production. The largest petroleum producers are also the largest gas producers. But gas wells are far less profitable than oil wells; they are classified somewhat more favorably than dry wells. In U.S. history and in our present circumstances it could not be otherwise; gas does not offer the same profit potential.

But the price of gas produced at depths below 15,000 feet is now unregulated, and is among the categories that sell at around $9 per million Btu. Much of the gas produced at lesser depths is regulated to lower prices, which go below fifty cents. Altogether, today there are 15 different regulated price classifications for natural gas. Except for the unregulated gas, which in addition to that below 15,000 ft. (commenced after 2/19/77), includes geopressured brine gas, coal seam gas, Devonian shale gas, and "other gas determined by FERC to be high cost," the price for gas as of January, 1982 was $3.00/MCF. At these low prices, and even at higher prices, the unregulated demand for U.S. gas should be much higher than it is today.

The root of the problem is in regulations like the Fuel Use Act, which currently bans the use of natural gas in new electric power generating plants and certain industrial facilities. Incremental pricing structure under the Natural Gas Policy Act of 1978 (NGPA) loads costs onto large users and subsidizes household use of natural gas, which is already a saturated market. Given the current gas over-supply situation, this loss of demand because of legislative restrictions also inhibits domestic conventional and supplemental gas supply projects.[7-1]

Dr. Phillip L. Randolph, Director of Unconventional Natural Gas Research, Institute of Gas Technology (IGT), has noted, ". . . gas production research virtually ceased from the 1950s to the mid-1970s due to low regulated prices." Thus, our future growth potential in gas, as well as our current production capacity, are both stifled directly by these regulations.

"There is presently an excess of gas deliverability, in part the result of regulations prohibiting gas use. The immediate problem is therefore removal of demand restraints, not a lack of production. Immediate deregulation of wellhead prices is unnecessary to satisfy anticipated demand levels. . . . immediate removal of restraints of gas use by industry and electric power plants should result in gas further backing out oil imports."[7-1]

"Out of a total of 7.4 million barrels per day of crude oil consumed in non-transportation uses in 1980 about 4.5 million barrels oil equivalent/day could have technically been replaced by gas."[7-2] This quantity is not only close to five times the daily use of aviation fuel, it now exceeds our rate of importing foreign crude oil. Releasing this potential would have a tremendous effect on the U.S. and probably the world petroleum markets.

As implied in the above statements the American Gas Association (A.G.A.) does not advocate immediate deregulation of natural gas prices; they oppose it. First, ". . . because most gas purchase contracts contain terms that require gas prices to escalate suddenly and rapidly upon deregulation — to prices well in excess of free market levels. . . . A.G.A. estimates that gas prices will double to all classes of consumers if wellhead gas prices were immediately deregulated. This shock will, therefore, reduce gas sales and increase oil use, which will in turn cause higher world oil prices and domestic gas prices."

Care must be exercised in transition from a regulated market to a "free" market, even though neither U.S. oil deregulation nor proposed gas deregulation will free the price on old oil and gas. The NGPA of 1978 sets the 15 categories of gas prices and establishes, month by month, in 1979, 1980, 1981, 1982, 1983, 1984, and 1985, the prices for each. It is generally characterized as deregulating "all" gas in 1985, but this is an oversimplification.

Even after 1985, in perpetuity, large categories of gas remain price-regulated. They include: "New Onshore Production Wells (Sec. 103), less than 5000 ft. and not dedicated to interstate commerce on 4/20/77; Natural Gas Dedicated to Interstate Commerce (Sec. 104); Rollover Contracts (Sec. 106), (where contract price is less than $1 per million Btu); Stripper Well Gas (Non-Associated) (Sec. 108); and Natural Gas Not Covered By Any Other Price Provision (Sec. 109)."[7-2] New onshore production wells will not be finally deregulated until July 1, 1987.

The above reference is purposely quoted in some detail to illustrate how laborious and tenacious the "deregulation" will be. But there is a more fundamental difficulty in the Act. Its definition of prices per million Btu (to the third place after the decimal; to the mill, or tenth of a cent), were established to conform with escalation in oil prices, but with the base set on the price of crude oil ***before the price rise of 1979-80!***

The author takes this opportunity to reproduce again Figure 1-1, also shown earlier as Figure 4-5, as Figure 7-1, which is considered to be the most significant single reality of this report.

Since enactment of these "deregulation" provisions, the world price of crude oil has more than doubled. Present legislation toward natural gas deregulation does provide for an annual inflation adjustment, ***but does not provide for escalation in crude oil prices.*** One category of natural gas (for interstate commerce, where production commenced before 1/1/73), will in 1985, still remain based on a price of $0.522 per million Btu. That is equivalent to oil at $3 per barrel, in 1985! So deregulation today, or even in 1985, can inject a sharp discontinuity into market prices.

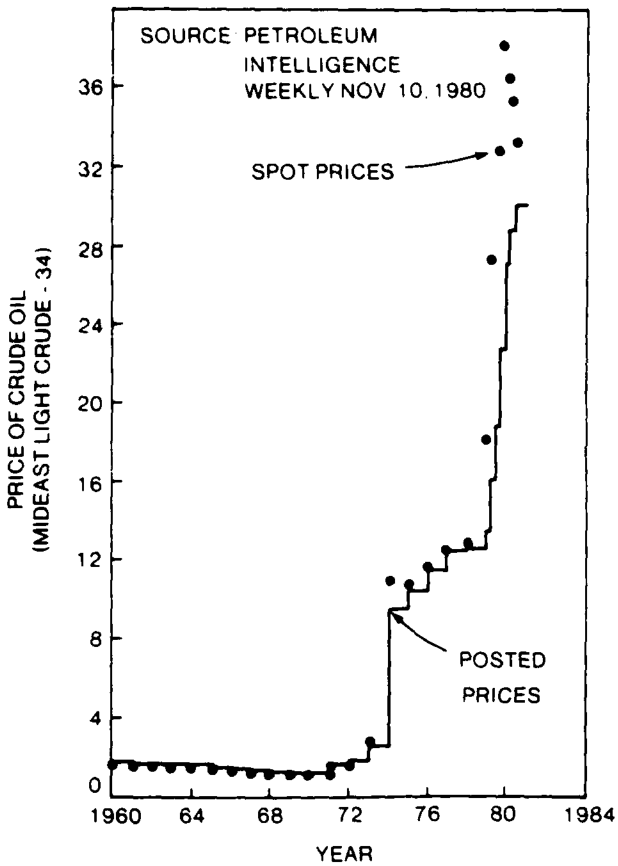

Figure 7-1

There is considerable argument about gas price deregulation on two points. First, the question of whether there will be a price "fly-up" unless further adjustments are made in the NGPA before 1985. On that score, the American Gas Association (transporters) argues that the present rate of increase in average gas prices will just about reach the 1985 equivalent of oil, for which the price has now stagnated, in 1985. The Natural Gas Supply Association (producers) argues that resources are limited and higher prices should be permitted sooner than 1985, up to a reasonable value on the energy delivered.

Lacking another disruption in world crude production before 1985, this author believes the A.G.A. study results are valid, particularly if energy conservation continues to depress demand for oil. That is, ***average*** gas prices at the burner tip should approximate burner oil prices in 1985. The author also believes, however, that long-term gas contracts with arbitrarily indexed prices should be abrogated by law and that natural gas prices should be allowed to rise more rapidly toward oil prices before 1985. This should be done only after regulations against gas usage have been removed and the consequent increase in demand has stabilized.

In case of another major disruption in crude oil deliveries before 1985, the NGPA should then be re-examined and probably revised, to prevent gas prices from getting out of hand.

The second dispute concerns whether gas prices should be indexed to the price of crude oil. If there were a free market, we would not be concerned with that question; we would soon find out. Some feel that, since gas is easily transportable by pipeline and it burns more cleanly than the best fuel oil, it will rise as high as the price of crude oil. Others conclude that a fair share of the value in oil is its portability and versatility as a transportation fuel, which gas does not offer directly

Natural gas, or as converted to methanol, may become a major factor in future transportation, but the time is far enough removed that deregulated gas prices are expected to reference more to coal, boiler fuel oil and nuclear-produced electricity than to transportation oil prices. (To prevent confusion, coal and No. 6 oil compete directly, so there are some petroleum products to which natural gas would relate.) But it is believed gas prices will rise as high as gasoline and middle-distillate prices, as many contend.

While the outcome of this speculation will determine the future supply/demand/price relationship for gas, its penetration into the oil market, and the oil it can back out and make available for air transportation, it is a detailed and tenuous matter to expound in this report. This author agrees with the Mellon Least Cost Energy Study,[7-4] which concludes that deregulated gas would follow closer to coal and related prices and that, in a free market, ***industrial use of gas should increase 75% by 2000***. Others who agree with this general conclusion are the Georgetown CSIS and the A.G.A.

As was indicated several paragraphs above, the A.G.A. does not advocate accelerated deregulation of natural gas prices because of the contract price provisions, which would trigger a chaotic market. President George H. Lawrence went on to say in a congressional hearing:[7-1] "While the phased removal of wellhead price controls on gas is important to a balanced gas market, this deregulation should be accomplished in a manner that recognizes the real world market disruptions that would accompany immediate, total deregulation. An A.G.A. analysis shows that total, immediate deregulation would cause the loss of 1.9 Tcf of gas load, increasing oil imports 800,000 barrels/day."

It may be difficult to relate to 800,000 b/d, but this is about the amount of jet fuel being used in the U.S. today. Or, it is about 20-25% of our oil imports.

Natural Gas Reserves

Forecasting natural gas resources is more difficult than forecasting crude oil because, in general, natural gas production has been based largely on petroleum. Oil and gas have been so linked in exploration that gas production is constrained by oil exploration regulations as well as by gas constraints. But, after a resource base has been established for crude oil, additional consideration of natural gas departs significantly. For example, the gas field at Prudhoe Bay is believed to cover about 500 sq. mi., about five times the area of the oil field. The gas pipeline, however, was not proposed until long after the oil pipeline. It still may not materialize.

Since the oil industry has produced more than 90% of the world's natural gas so far, the terminology used and the viewpoint are often that of the oil producer.

Natural gas categories first break overall into "conventional" and "unconventional" gas. Conventional gas is produced from current oil-producing wells; from wells that once produced oil, but now produce largely or only gas; from wells that were drilled for oil, but produced gas only; or from wells that were drilled for gas in oil-bearing regions or on oil leases. Conventional breaks down into "associated" and "non-associated" gas.

Associated gas is produced either dissolved in oil, along with oil, or from an oil well after the oil production ceases. Non-associated gas is gas produced from oil-type geology or leases which did not and presumably were not expected to produce oil. Although previously most gas produced was associated with oil, for the past decade, about two-thirds of this production has been

from non-associated sources, partially because of regulatory and tax effects.

Unconventional gas had been defined as all gas produced from areas that are not essentially oil-producing areas. There is now some ambiguity in at least one category, tight-sand gas, whether it is still unconventional; it will be discussed later with the unconventional sources. Incidentally, as EOR signifies enhanced oil recovery, UGR identifies unconventional gas resources.

Aside from OPEC and the Soviet Union, it is believed that Exxon produces more natural gas today than any other organization. As suggested above, natural gas has always been produced from oil wells, as a driving force in the early stages of production and dissolved in the oil during essentially all production. That is, since gas dissolves readily in oil, gas is regularly produced along with the oil, and the two are separated at the wellhead.

This gas may be reinjected into the oil field to help maintain pressure, in itself a form of pumping and EOR. It may be cleaned up and pipelined directly, or liquified into LNG where pipeline facilities are not available. In the future, as has been suggested, much more natural gas may be converted into methanol at the wellhead or nearby. Lastly (but unfortunately often firstly), gas may be flared or released to the atmosphere. Oil production cannot continue without some disposition of the natural gas that accompanies the oil as it comes from the ground, either as a gas, in solution, or both.

One of the significant weaknesses in gas production statistics is that so much natural gas has been flared in the past, and continues to be flared, in unknown quantities. Estimates can and have been made, but they may not be reliable. This is perhaps the first point at which gas information suffers relative to oil statistics.

In view of world energy prices and needs, the amount of gas flared in the past and continuing to be flared today is appalling. Astronauts regularly comment on the vast quantities that can be seen flaring at night as they circle the globe. A photograph in ***National Geographic*** of November, 1978[7-5] shows what a spectacular display it makes for a space traveler. From that article, "Great sunbursts of flaring gas spangle the Persian Gulf in a midnight satellite image made in 1974. Though the practice is restricted in the U.S., some seven trillion cubic feet of oil-field gas went up in smoke last year worldwide — an energy equivalent of two years of Alaskan North Slope oil production. Oil economics being what they are, 'waste' gas often remains cheaper to burn than to transport." Canada still flares some of its natural gas production.

If a natural gas pipeline is convenient leading to customers, the solution is simple. Constructing a new pipeline costs capital and there must be a customer at the other end. Failing that combination, the only viable option in recent years has been liquefaction, which has required a very large investment in machinery and, not incidentally, a fair amount of natural gas used to power the compressors for liquefying the gas. As a significant part of the liquefaction process, the gas must be chilled to −258°F or lower. In turn, storage tanks, tankers and plumbing must be heavily insulated. Because of the low temperature, it is uneconomic to pipeline liquid methane over conventional pipeline distances.

Further, specialized LNG tankers must be available to receive the product from a loading terminal, which is itself a sizeable investment. LNG tankers are also expensive, are not often readily available, and have long construction lead times, while an active customer with his terminal must be on the other end of the sealane. Due to the size of these investments, the supply contracts must be long-term and the gas supply must be very large and likely of long life in order to amortize the capital costs.

Long-term contract negotiations can lead to complete deadlocks such as that between the nation of Algeria and the El Paso Natural Gas Co. in 1981. After preliminary negotiations justified sustantial investments by El Paso in cryogenic tankers and other equipment, the Algerian government arbitrarily concluded their negotiated gas price should be raised to parity with the highest crude oil prices — $6.11 per million Btu, which corresponds to $36.50 per barrel of crude. Negotiations broke off completely and, as of early 1982, El Paso has sold some of its tankers and is seeking buyers for the remainder. They are turning to domestic sources for their gas and have written off a $365 million loss on the Algerian deal.

Italy has now completed construction of an underwater pipeline from Sicily to Algeria. Unfortunately, they too, failed to negotiate a firm contract with Algeria before the commitment and, as of this writing, they had not come to terms.

Investment problems of this magnitude leave strong impressions in the industry, leading to great care and caution in forecasts or in contracts involving future natural gas supplies and prices.

Natural Gas Market

As has been suggested, the quantity of natural gas resources in both the United States and the world is so large that its depletion should not enter into market considerations for two, three, or more generations. That opinion is not held by all, however, and our present U.S. regulations against certain uses of natural gas are vestiges of the past. In the winter of 1976-77 and again in New England in 1979, there were acute shortages of gas for even home heating.

But the problem was in no way a shortage of resources or even of production capacity. In the first case there was some limitation in distribution capability, but the real problem was in price regulation. There were tight federal ceilings on interstate gas, but intrastate gas prices are unregulated, and intrastate prices went out through the roof.

As an illustration, Canada, which had been selling natural gas in the United States for 22 cents/MCF, raised their price to $4.47. Negotiations with Mexico broke down when they, too, sought to index the price of their natural gas to the price of crude oil, with no regard to their production costs or past prices. A contract has since been signed with Mexico on the same basis as the memorandum of understanding with Canada.

Foreign producers can end up in a favored status over domestic producers. In effect, interstate U.S.-produced gas has been held regulated while the rest of the world insisted on world oil replacement prices.

Consequently, customers in gas-producing states could buy all the gas they wanted at exorbitant prices, while customers in import states only got the excess that some producers were willing to ship at the low, regulated prices. Why sell it interstate at a third or a tenth the price for which it can be sold intrastate, at home, in the future? Naturally, taxes and other costs enter into this sort of decision-making.

In the second, New England shortage, an unusually sharp drop in temperatures could not be tracked by the storage and transmission facilities. Again, one might say that the basic problem was in pricing, because transportation capability and storage facilities would have been built if the market had been attractive to sellers. In the first case, the difference in interstate and intrastate prices produced the shortage directly; in the second case, it created the inability to respond to a rapid rise in demand.

In both cases, however, constituents complained loudly to Congress and a strong impression was created. The inference was that gas is a scarce and valuable commodity; so many depend on it for basic home heating and cooking in populous areas that its distribution and pricing cannot be left to the natural market. Gas was considered so valuable that priorities were set to protect households, and restrictions were levied on industrial use accordingly.

But the concept of gas shortage was completely at odds with the facts. There was no natural market. Price regulation contributed to or first caused the shortages, while further regulation has assured that a real solution will not be obtained until it is rescinded. These waves and counter-waves have so ruffled the surface of the gas "market" that now it is a contradiction to call it a market.

The popular perception, which is probably not now shared in Congress but reflects their constituents' views, is that the U.S. is critically short in its natural gas resources. Gas is perceived as a treasure to be rationed carefully, like drinking water in a lifeboat. The situation is much like that in nuclear energy, where members of Congress are probably well-informed on the issues of safety and proliferation. But, until their constituents thrash out misconceptions for themselves, it is a courageous congressman who dares to buck the tide.

Even as late as January 1982, George H. Lawrence, President of the A.G.A., in an address to the National Oil and Gas Price Policy Institute, felt constrained to say: "Natural gas, dismissed as a future energy alternative during the curtailment period of mid-1970's, has only recently begun to regain some of the markets lost during that period. These gas markets, principally industrial and power plant customers, switched to oil because of the non-availability or insecurity of gas supplies at that time. Today ***because of Federal and state regulations restricting gas use***, availability and security of gas supplies are still matters of concern to the industrial sector."[7-2]

The following evidence is presented to dispel remaining doubts readers may have about our practically boundless (author's opinion) supply of natural gas. As pointed out for oil resources, even conservative views on natural gas supplies are basically speculative.

But the signs of plentiful gas are so strong and positive that this author believes the ***resources*** of natural gas must be relegated to among our least concerns. If one agrees that the near-term oil market is an economic balance made by price, then the same forces (if allowed to prevail) will doubtless produce a natural gas market for twice, three times, or X times as long a period. That is, if petroleum supplies (and conservative demands) will permit a stable market for twenty to thirty years, a similar market in natural gas should prevail for fifty to over a hundred years.

Natural Gas Sources

It is curious that the World Energy Conference, in the Summary of its Istanbul report for 1978,[7-6] made no particular note of the statements contained in its chapter, "The Future for World Natural Gas Supply." The Conference's Summary reflected essentially the "conventional" or "statistical" view of oil depletion at that time: U.S. production had peaked in 1970 and the world's oil production would peak in the 1990s. After the peak, oil production could do nothing but decline out to extinction. And the Summary concluded that oil and gas follow the same trends, as has been the traditional concept.

But, back in the discussion portion of this same report, the outlook for natural gas was much more encouraging. Written by committee members from the American Gas Association, the Results and Conclusions begin: "There is a worldwide capability for substantially increasing production of conventional natural gas in the next ten years and sustaining production levels well above today's level at least until year 2020."

Proved reserves were shown to represent 50 years supply at the world's then current production rate, while undiscovered reserves were estimated to last another 160 years. Put another way, by 1975, the world had used about 40% of its presently estimated proved oil reserves, but only 11% of its proved gas resources. This is an important conclusion in any scenario. ***Whatever the quantity forecast for future oil discoveries, the forecasts for future natural gas are generally agreed to be three times or more greater, in equivalent energy available.***

"Even at an annual world natural gas production rate of double the present rate . . ., the estimated world remaining conventional natural gas resource base would be sufficient to sustain production at or near this level for at least another fifty years."

"This conclusion does not assume any production from the numerous sources of unconventional and supplemental sources of natural gas from geopressured resources, from tight gas formations, from coal beds, from shales, and from biomass. They represent an additional substantial gas resource base estimated in the range of several thousand to tens of thousands of Exajoules." Compared to about 10,000 Exajoules estimated for the world's known and undiscovered ***conventional*** gas resources, this would indicate a practical total world supply of twice to three times the 50 and 160-year lives of conventional supplies.

The report went on to state (in 1978) that a gas price of $20/bbl crude equivalent in 1974 dollars would permit world gas production to double between 1985 and 2000. Based on these figures, production would begin to decline after 2000. But, both of these conclusions considered only the conventional sources of gas and the unconventional sources were set aside. Today we are beginning to see substantial production from some of these unconventional sources, even under unfavorable regulation.

Some are now saying that gas from tight formations (tight sands) should no longer be called unconventional. It is produced from formations that are not oil-bearing, but production levels from the Rocky Mountain states are now so high that the industry is regarding it as a full-fledged, "conventional" source. The secret? Its price is unregulated today and is much of the gas claiming price tags up to $9 per MCF.

A few additional references will be cited to round out the view on conventional gas resources.

From Dr. Harry C. Kent, Director, Potential Gas Agency, Mineral Resources Institute, Colorado School of Mines:[7-7] "The work of the Potential Gas Committee (Dr. Kent, Chairman) indicates, based on 1980 information, that more resources exist in the deeper parts (depths greater than 15,000 feet) of sedimentary basins than was previously estimated. . . there have been disappointing results from offshore exploration and drilling in the Baltimore Canyon of the continental margin and in the Gulf of Alaska, both areas where it was previously thought that there was considerable potential for natural gas." Since that time, new gas strikes in the Baltimore Canyon indicate that while its prospects are still disappointing in oil, it now promises to pan out in the gas resources originally forecasted.

Dr. Kent's comments conclude, "If we look at the total of present proved reserves and potential supply, it would appear that possibly twice as much gas could be produced in the future from conventional sources as has been produced in the entire history of the industry." Please note that this comment is confined to the conventional resources.

Mr. William T. McCormick, Jr., Executive Vice President, Michigan Wisconsin Pipeline Company, "Although natural gas use could conceivably grow to satisfy as much as one-third of total U.S. energy requirements, positive efforts need to be *undertaken immediately*. . . . The major uncertainties in these estimates are those associated with future Federal and State regulatory policy decisions."[7-8]

He noted that very significant gas discoveries in the Rocky Mountain Overthrust have not been entered into the books yet.

He also pointed out that, in a well newly drilled, the upper gas-bearing zones are not flow-tested and are not added to the well's production or resource estimate. This is not a perversity, but a procedure of licensed oil and gas geologists. The well is drilled to its design depth and assessment is made at that depth, simply a standard geologic-accounting procedure. Although up to five or more pa zones may be encountered on the way down, they are typically not assessed until the lowest zone has been produced! Phil Boudreaux of the Louisiana Department of Natural Resources advised the author that one well in the Tuscaloosa Trend has logged 13 pay zones.

For early impact, the A.G.A.: "All told, it is estimated that the gas energy equivalent of 2.3 millions barrels of oil/day could be made available by 1985 if the nation were to make the required commitments."[7-9] From another A.G.A. publication: "Had the nation used only the most economical end-use technologies and fuels during 1978, for example, we would have used 28 percent less oil, roughly 43 percent less electricity, but 14 percent more natural gas than we actually used in 1978, according to ***The Least-Cost Energy Strategy***, a report issued last year by the Mellon Institute. If these findings were updated to 1980 fuel prices, they might differ considerably because oil prices have risen faster than either gas or electric rates."[7-10]

And another observation by the President of the A.G.A. in 1982: "In the past, similarities in oil and gas industry technologies, in growth trends, and in drilling activities have resulted in the erronious perception that U.S. and world oil and gas resource depletion patterns are similar. . . . World resources of natural gas in place at year-end 1979 are estimated at 90.1 percent of the original recoverable resource. About ten percent has been produced, with over half of the production occurring in the United States."

"World resources of oil in place at year-end 1979 were estimated to be 83.7% of the original recoverable resource. Cumulative world oil depletion at year-end 1979 was more than one and a half times that of natural gas on a percentage basis —16.3 percent as opposed to 9.9 percent. . . . If this difference in consumption rates continues, world natural gas resources would only be about 20% depleted at the turn of the century. By contrast, oil resources at the turn of the century would be reduced to about two-thirds of the original recoverable resource."[7-2]

And to the Senate in November 1981: ". . . gas provides two and one half times as much end use energy to consumers as electricity. . . . All indexes of gas exploration are at all-time highs. Seismic crews number 744, up 32% from a year ago. The number of active drilling rigs as of October 12 was 4368, up 40% from a year ago. . . . the ratio of exploration gas well completions to total gas well completions is up significantly. . . . When the NGPA was being debated, we emphasized that then-existing policies had created a situation in which almost all drilling was occurring in areas where it was inexpensive to drill, rather than in areas where gas potential was greatest, such as deep or tight formations. The NGPA, however, has turned these statistics around by providing incentives for exploratory gas drilling."[7-1] (But only in those categories which are unregulated, where gas prices go to $9/MCF — Ed).

The energy and fuel situation in New Zealand is an interesting one for the energy-r. h U.S. to consider, as expressed by B.E. Brill, Parliamentary Under-Secretary to the Minister of Energy:[7-11] "New Zealand is particularly vulnerable to movements in oil price and supply. Imports must supply 85 percent of total liquid petroleum needs, about 75 percent of which is used in the transport sector. The oil problem in New Zealand is therefore very much a transport fuel problem. This contrasts with the situation in many other countries where industrial and household fuels are of equal importance."

"Although New Zealand has an energy problem, paradoxically the country is well endowed with energy resources in the form of natural gas, coal, hydro, geothermal and the potential for energy farming. Unfortunately none of these resources is in a form readily suited to transport use. . . . the Government in 1978, embarked on a determined programme aimed at using indigenous resources to reduce dependence on imported oil. . . . The major outcome of the programme has been the decision to proceed with synthetic gasoline manufacture based on natural gas. . . . It is pertinent to reflect that if every other major oil importing country took action to follow this example then the current world oil problem would disappear."

Unconventional Gas Resources (UGR)

Unconventional gas resources are usually listed as: Coal Seams, Devonian Shales, Western Tight Sands, Deep Basins, Geopressured Zones and Methane Hydrates. The DOE UGR program does not address methane hydrates.

In addition, "Substitute Natural Gas" (SNG), which is also methane, can be synthesized from coal, lignite, peat, shale, or, for that matter, from any other fossil fuel, including petroleum. That is, some of the oil uneconomical to produce by EOR can be partially recovered as methane by in-situ production methods. SNG, synthetically-produced methane is not classified with UGR and will be discussed briefly and separately.

Garbage and other biomass, such as wood wastes, crop wastes, manure and sewerage, are also sources for methane or methanol, which are now being produced competitively; these sources are generally regarded as "renewable resources."

The term "UGR" is generally limited to methane which is deposited within the earth's crust.

The November, 1978 ***National Geographic*** article, "Natural Gas: The Search Goes On,"[7-5] which has been mentioned earlier, is still an outstanding reference as a popular summary of UGR in both the U.S. and the world contexts. Although it was a trail-blazing article at the time, it is still amazingly fresh in its contents and quantitative data. It is highly recommended as a general summary, while it illustrates the geological structure of UGR sources and includes a map of their distribution in the U.S.

From that article: "'Natural gas? We could have it running out of our ears,' says Dr. Paul Jones. 'But first we've got to accept some new ideas about petroleum geology.' He stabs a finger at a map of the Texas-Louisiana coastal region, which is barely recognizable beneath a crazy-quilt pattern of subsurface contour lines."

"'Those lines could lead us to more gas than we've ever dreamed of, enough for centuries,' says Paul. 'They mark the geopressure systems — 150,000 square miles of porous shale and sandstone saturated with hot brine at abnormally high pressures. *There's good evidence that this brine could contain* as much as 50,000 trillion cubic feet of gas. That's equal to 2,500 times our present yearly production.'"

"As a hydrologist, Paul has spent thirty years — most of them with the U.S. Geological Survey — studying the critical role of underground water in the earth's geological history. Some of his ideas are still sheer heresy to many petroleum experts. But he is one of a growing band of scientists, engineers and hard-nosed production men who reject the dire predictions that United States gas resources will soon be exhausted."

Dr. Jones lives in Baton Rouge, where the Louisiana Geological Survey and the Louisiana Department of Natural Resources do not share his enthusiasum; but those differences will be discussed later under geopressured gas. As recently as 1977, UGR was still being dismissed as "moon-beam" gas.[7-12] Dr. Jones is by no means alone, however; others have also stated that UGR should provide at least one order of magnitude greater quantities of natural gas than conventional sources.

Some say without qualification that natural gas is currently our largest potential energy source, surpassing oil, coal, or nuclear energy. They point out that, in fact, in 1979 we did consume more energy in natural gas (19 Quads [quadrillion Btus], 18 for domestic oil, 14 for coal, and 3 for nuclear). They consider the constraints on gas usage, and the estimates of resources as being evidence that the U.S. is simply denying itself a domestic bonanza.

More conservatively, according to the Gas Research Institute[7-13] in March 1981, "All recent estimates of the size of the unconventional natural gas resource base agree that it far exceeds the present U.S. proved reserves of conventional natural gas and that resource base limitations will not be a constraint to production from these unconventional sources. However, economic considerations will allow recovery of only a fraction of the resources in-place. Nevertheless, the recoverable resources estimated by GRI are still substantial, as illustrated in Figure 1." Their Figure 1 is reproduced here as Figure 7-2.

"Because current prices for categories of decontrolled natural gas are already on the order of $6.00 per Mcf (in early 1982, $9), one can conclude that the entire 115 Tcf shown in the figure for existing technologies should be considered recoverable. If advanced technologies to produce these resources can be developed and commercialized, the total recoverable resources more than double to 225 Tcf. This is almost 50 percent larger than the 1979 proved natural gas reserves outside of Alaska."

". . . As shown in Figure 2 (here Figure 7-3), these sources could begin to provide noticeable additional amounts of natural gas in the mid-1990's. Under optimistic, but achievable, circumstances production by the end of the century could approach levels equal to about half of the total U.S. natural gas production levels. Figure 3)." (here Figure 7-4)

". . . Figure 4 (here Figure 7-5) demonstrates very clearly that there is an excellent chance to hold U.S. natural gas supplies reasonably constant through this decade, and that in the 1990's, *natural gas supplies* should begin to grow at rates approaching or even exceeding 3 percent a year, reaching 25 to 30 Tcf (1980 consumption was 20 Tcf) by the end of the century."

And Henry R. Linden, President of GRI adds:[7-14] "In the United States alone, this means we have at least 800 trillion cubic feet of conventional natural gas, plus 200 trillion cubic feet of tight sands, Devonian shale and coal seam gas that can be produced at prices not too different from today's levels for new gas."

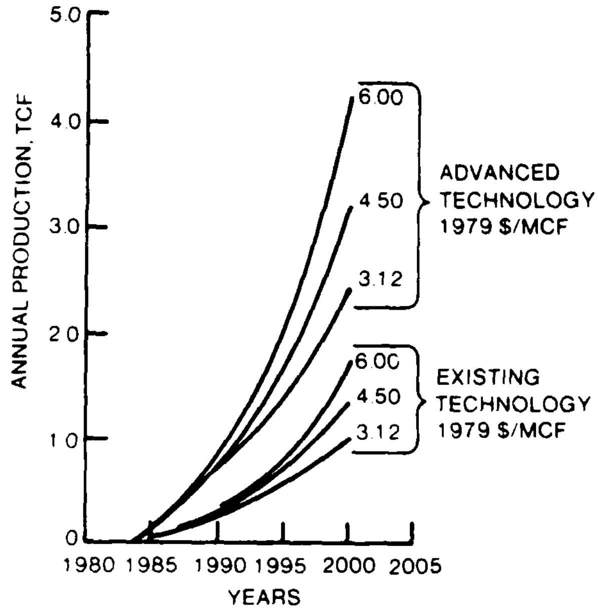

Figure 7-3a
Conservative Estimates of Annual Production from Western Tight Gas Sands

Figure 7-2
GRI Recoverable Resource Estimates for Tight Formations and Coalbed Methane, TCF

	MARKET PRICE (1979 $/MCF)	EXISTING TECHNOLOGY	ADVANCED TECHNOLOGY
WESTERN TIGHT GAS SANDS	3.12	30	100
	4.50	45	120
	6.00	60	150
DEVONIAN SHALE	3.00	10	20
	4.50	15	30
	6.00	25	45
COALBED METHANE	3.00	10	30
	4.50	15	40
	6.00	30	60

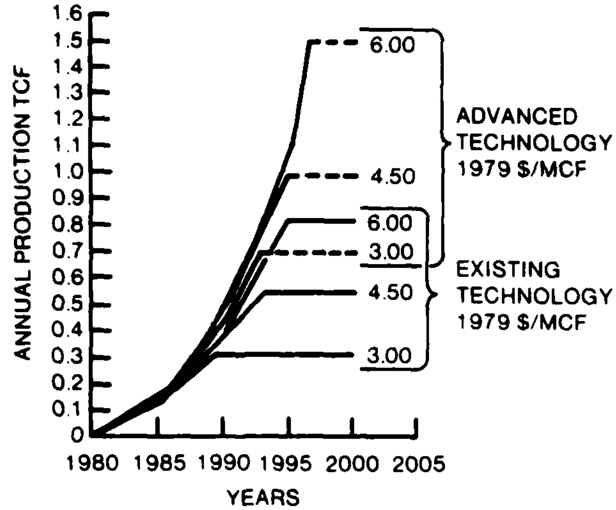

Figure 7-3b

Annual Production Estimates from Devonian Shale

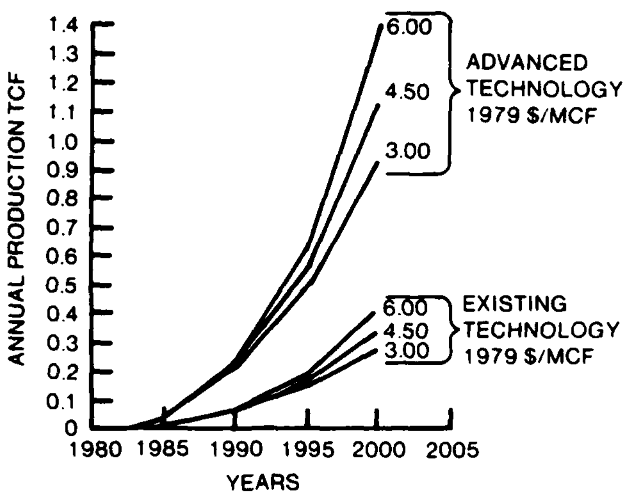

Figure 7-3c

Annual Production Estimates for Coalbed Methane

Figure 7-4

GRI Estimate of Potential Gas Supplies from Unconventional Sources in the Year 2000

	TCF
WESTERN TIGHT GAS SANDS	2.0-6.0
EASTERN DEVONIAN SHALE	0.3-1.5
COALBED METHANE	0.3-1.4
METHANE FROM GEOPRESSURED ZONES	0-1

The next six sub-sections will briefly discuss the categories of UGR listed in the first paragraph of this section.

Coal Seam Gas

The DOE has noted in its annual report[7-15] that in the U.S., 100 billion cubic feet of natural gas escapes or is vented from coal mines each day. That adds up to more than our annual natural gas consumption; we *waste* more gas from coal seams alone than we consume! It is also equivalent to 17.2 million barrels of oil per day, more than four times the energy of our crude oil imports!

K.C. Bayer of the U.S. Geological Survey has joked[7-16] that between five and ten thousand wells are producing commercial natural gas from coal seams and Devonian shale today; they are still classified as "unconventional."

Coal seam gas is "unconventional" in the sense that it has not been exploited by the conventional petroleum-oriented natural gas community on the one hand or by the conventional coal producers on the other. Methane is encountered in all coal beds to a greater or lesser extent. In some mining areas, it is prevalent enough to advise gas extraction before or during the mining process, for safety.

Coal operators have a legal right to release methane in the course of mining, but they generally do not hold legal rights to the gas and cannot sell it. Virtually all the gas drained from U.S. coalbeds has been wasted; gas operators have shown no interest and, to the coal industry, it is a problem of mine safety. The problem is not entirely lack of enterprise. The rights to gas can be an extremely complicated legal puzzle, particularly in some of the older eastern states.[7-17]

Many coal seams are too thin to mine, heavily interlayered with rock, or are too sharply tilted for mining by conventional methods. Some coal beds in the West are too deep for surface mining, and too thick to mine by conventional deep-mine methods; generally the limit is around 100 feet thick because of the supporting pillars which must be left. All of these are candidates for coal seam gas extraction.

Western coal beds, ironically, are not economically competitive with the deep Western tight sands because of pricing regulations. As pipelines are installed to bring out tight-sand gas from the Rocky Mountain Overthrust, it may then become economic to tap the coal beds for methane. That's a rather sad commentary on our regulatory process; we are now denying ourselves, both in the East and the West, fuel sources which would most likely undercut the price of imported crude oil!

H.H. Rieke of TRW[7-18] notes that the Arkoma Basin (Ark.-Okla.) is about 250 X 50 miles and extends east to Little Rock. Potential natural gas from this coal bed area has been excluded from potential gas supply surveys due to lack of data on the resources, the technology required to extract it, and on the likely economics. But the resource is likely to be considerable.

The Illinois Basin is an interesting prospect. The USGS estimates its coal resource at 365 billion tons (as compared to 7 9 billion tons in the Arkoma Basin). But the gas content of the Illinois Basin is relatively low, with the best potential in southwestern Illinois and western Kentucky. The methane source is estimated greater than 5 and as high as 20 Tcf. This is not great on a long-term national basis, although it could reach as high as 3.5 billion barrels of oil equivalent. But this kind of resource could be economic and represent a tremendous benefit to local industries and communities. Compared to wind, water, geothermal energy and the like, it is a veritable bonanza.

Coal seam gas may fulfill that sort of "local bonanza" role in many locations within the U.S. Where there may not be enough gas to justify running in a large pipeline, local communities and

industries are finding that a relatively cheap gas well can solve their heating and energy problems. When cogeneration of heat and electricity becomes more widely accepted, these local installations may take care of most of their energy needs.

As liquefaction of natural gas becomes more economical, the case for local production of automotive ***and aviation*** fuel can take on real significance.

In fact, the commercialization of small gas wells is becoming more attractive rapidly, and this in spite of the regulatory situation. Small liquefaction plants have now been developed which can be trucked into the West Virginia mountains. Where connections to pipelines are too expensive, these units will play an important part in getting small quantities of methane to market.

On an even smaller scale, Texas Gas Transport Co. and Pressure Transport, Inc.[7-19] have reported on their small compressor system which can be used for wells down to a flow rate of less than a million cubic feet per day (172 barrels oil equiv.), hauling the compressed gas for distances up to a hundred miles. This is accomplished by using one truck tractor and one driver-operator, together with one portable compressor plant at the site and two trailers, each of which carries ten standard cylinders of about 77 cubic feet at 2800 psi.

The driver leaves one trailer filling from the compressor unit at the wellsite while he hauls the second, full trailer to the nearest pipeline access, up to 100 mi. away. He returns with the empty trailer, connects it to the compressor plant and hauls off the second full trailer for delivery. At distances of ten miles, he can handle about three times the flow as at 100 miles. But below ten miles, a pipeline hook-up begins to look competitive. Transportation costs were shown to be in the range of $1 per million Btu for a haul distance of 20 miles.

This type of operation makes economic some small producers which could never pay for liquefaction, let alone a pipeline hook-up. It is also useful in the early life of a field before the pipeline connection is rigged or before the production rate has built. There may later be some application after production has fallen below pipeline interest. Further, this type of transport may provide a market for methane from sanitary landfills, animal feedlots and municipal sewer plants, which otherwise would be stranded.

As suggested earlier, more economical and portable methods are being introduced for liquefying methane. Both compressed and liquefied methane should become significant in our energy future.

Devonian Shales

Devonian shale is the predominant shale in the Appalachian region and the entire eastern part of this country. It offers some potential for producing shale oil, as will be seen in the next chapter, but by a more sophisticated process than extracting oil from western shale. Gas has been extracted from eastern Devonian shale beds in small quantities for generations and Appalachian gas resources in Devonian shale are generally abundant.

Devonian shales typically have low permeability — they are dense materials. So wells have low productivity over a long life. Because of this density, some estimates expect that only 4% of the gas is recoverable with present technology. Problems include the long payback period on the investment, low price of gas, rising well drilling costs and the need for new technology in fracturing the rock underground so as to speed production. At present, wells are stimulated by shooting with explosives or by hydraulic fracturing.

Well costs vary widely depending on geology, accessibility, labor rates, local work rules, overhead, royalties, taxes, etc. In general, Devonian shale is economically marginal. As reported by Miller and Mutchler of Berger Associates in 1980,[7-20] most Devonian operations were not economical at the then-regulated price of $1.42/Mcf; marginal for efficient operators at $1.75/Mcf, and generally profitable at $2.00/Mcf. One would generally expect, then, that gas price deregulation should bring in considerable eastern shale gas along with coal-seam gas.

Higher-cost producers, such as large utilities, have not been producing their Devonian properties. The producer-consumer (small operator who usually consumes his production on site) is not governed so much by price as by assurance of supply. So some of the smaller operators have found Devonian shale gas desirable. The above costs and conclusions regarding Devonian shale generally agree with a study made by the congressional Office of Technology Assessment.[7-21]

Figure 7-5

Ranges of Potential Gas Supplies

SOURCE	TCF/YEAR 1979	1985	2000
NATURAL GAS			
CONVENTIONAL	19.4	16-18	12-14
ALASKAN	0.1	0.1-0.6	1.1-2.0
UNCONVENTIONAL	—	0.2-0.6	2.1-2.8
PIPELINE IMPORTS			
CANADIAN	1.0	1.0-1.5	1.0-1.5
MEXICAN	—	0.1-0.5	0.5-1.0
LNG IMPORTS	0.2	0.5-0.8	0.5-1.5
SUBSTITUTE NATURAL GAS			
FROM PETROLEUM	0.2	0.1-0.3	0.1-0.5
FROM FOSSIL FUELS (COAL PEAT OR SHALE)	—	0-0.1	1.1-1.5
FROM AND WASTES	—	—	0.1-1.0
TOTAL	20.9		
POTENTIAL RANGE OF SUPPLY CAPABILITY		18-22	25-30

OTA considered the effects of various deregulation schedules and concluded that total deregulation would stimulate conventional gas at the expense of Devonian gas. But Devonian deregulation alone would stimulate up to 17 Tcf of UGR by 1998. That is equivalent to almost three billion barrels of oil, or 8 million barrels per day, *more than twice our foreign crude imports*.

Some of these smaller sources look pretty big when viewed in context.

Western Tight Sands

A few years ago, Western tight sands were viewed with more skepticism than other types of UGR. They are in the Rocky Mountain region, often with poor accessibility and far from markets. The geological prospecting is difficult. Drilling is deep and expensive. The "sands" are literally as tight as concrete; the rock permeability is low, so production rates are either prohibitively low or must be stimulated. It was at these tight-sand resources that the nuclear "Plowshare" underground explosion tests were directed to see if these rocks could be fractured and stimulated to release their gas more rapidly. Unfortunately, Plowshare's heat also fuzed and sealed off the strata. Today, fracturing is usually hydraulic.

With all these handicaps, deep tight sands are now bringing in commercial quantities of gas, about 1% of the U.S. supply. Production becomes economically feasible due to favorable provisions in the pricing structure. Effects and interpretations of regulations are not uniform, which contributes to inequities in the industry.

This also leads to a definition problem, as was mentioned earlier in this chapter. In enhanced oil recovery, EOR is always EOR. But unconventional gas recovery (UGR) is defined more *from the standpoint of research and development*. R&D ceases to be R&D when it progresses into production. Those in the gas industry regard UGR in that light. Now that tight sands are beginning to produce in commercial quantities, the industry is beginning to call them conventional resources. This then leads to other difficulties in definition, since some tight formations are still very much unconventional.

Significant gas is also being produced from coal seams and shale deposits, but they are still generally regarded as UGR. One of the reasons is that gas produced by a producer-consumer is still regarded as outside the pipeline system. Some of it is quietly kept or even secret. Some of the "unconventional" gas reaching the pipelines is unpublicized and probably not reported to DOE. So the definition of UGR has become a rather soft and variable thing; it depends as much on one's viewpoint as anything else.

Deep Basins

It is difficult to speak of a gas industry as distinct from the oil industry since some parts of the two are so inextricably woven together. But there are gas people who are not oil people. And these gas people have probably always considered gas from deep basins as conventional gas. From the oil community and probably from much of the public's viewpoint, gas from deep basins is unconventional.

It is certainly not "associated" gas, because no oil is present. In fact, as drilling goes deeper, more gas and less oil is usually found. The deeper deposits are subjected to higher pressures and temperatures and, in general, they have been in place much longer. Under these conditions, the oil that might have been there earlier would be expected to have been converted to gas. In that sense, gas from deep basins may be regarded as unconventional. It takes unconventional prospecting and drilling to produce the gas. Certainly no one would be drilling into the deep basins in the hopes of finding oil — it is for gas.

As reported in ***National Geographic***, Robert A. Hefner has drilled more than thirty successful deep wells in the Anadarko Basin in western Oklahoma. "We think we'll find between 70 and 360 trillion cubic feet of gas in the Anadarko between 15,000 and 40,000 feet. We're as sure as 150 million dollars in research and exploration can make us. We're even predicting gas production below 50,000 feet, with better technology."[7-5] "This is not conventional production," Hefner continued, "But this basin has 22,000 cubic ***miles*** of sediments below 15,000 feet — and only one percent of it has ever been touched by a drill."

In May 1978, Hefner completed a gas well which he calls a "super well;" it produces the equivalent of more than one million barrels of oil a year!

Geopressured Zones

"Rapid sedimentation along the Gulf Coast induces the formation of faults and the isolation of layers of sandstone where salt water saturated with dissolved gas collects. Increasing pressure expands the faults until some of the fluid escapes; the resultant depressurization permits some of the methane to come out of solution and exist as free gas bubbles in the rock pores. Drilling into the sandstone brings further depressurization, which causes the gas bubbles to expand and join, creating a fountain of natural gas. Gulf-region geopressure zones, usually below 8,000 feet, may contain 60,000 TCF."[7-5] That is more than a 3,000-year supply at the U.S. present consumption rate, so it is certainly something to contend with.

Geopressured gas is controversial, not so much in the fact of its existence, but mostly in the practicality and costs of its production. From conversations with the Gas Research Institute, the quantity available may vary from 40 Tcf to 3,000 Tcf, on up to the 60,000 Tcf mentioned above, depending on to whom you talk and the conditions he may have in mind for producing the gas.

These conditions would be concerned largely with economics; most of the question is what the costs might be under different gelogical circumstances, as well as what the market price might be under a variety of possibilities. Decontrol of gas usage and gas prices naturally brings forth a larger estimate than does production within the present framework of regulations and prices.

Several tens of thousands of wells have penetrated geopressured zones, but the resource has been largely overlooked and treated as an inconvenience. If you're looking for oil, you are not likely to be interested or equipped to deal with geopressured brine.

It is well to keep in mind that ***Government estimates of resources and markets, be they from the USGS, DOE, Interior, or elsewhere, are by definition based on legislation as it now exists***. Particularly, the DOE annual reports and other releases mention this fact so that, those who are estimating resources under future deregulation or other legislation, will necessarily obtain different answers than government offices.

In addition to these institutional uncertainties, however, geopressured sources for methane are concerned with a series of technical problems. Much of the gas is dissolved in salt water at high temperatures and pressures. Since the solubility of gas is dependent on these parameters, a great deal of dispute centers about the conditions, particularly the salinity of the water in various areas.

These conditions lead to other variations because a geopressured well must produce a great deal of water per volume of dissolved gas. Assumptions made on disposition of the water can change the economic result considerably. Further, the temperature, pressure and, particularly the salinity, have strong effects on erosion and corrosion, the difficulty and costs of producing the well, as well as of maintaining the well.

Another source of speculation is the geologic structure of the region. Sediment has been laid down during eons of silting from the Mississippi River basin. As deposits accrued, sliding and slipping has taken place, producing many faults and myriads of fractures. In some cases, these may have consolidated gas into large deposits; in others they have fractured the deposits into small, isolated pockets. This silting and fracturing is a constant process. The Louisiana Geological Survey stressed this fact to the author and remarked that the area constantly experiences small tremors, virtually daily.

A drill may therefore penetrate a large reservoir of water geopressured with methane or may penetrate a very small, isolated source. At the high costs of drilling wells to considerable depths under adverse conditions, risks are high. Most of the work undertaken to date has been in conjunction with the DOE. Now that DOE funds are scarce, it is questionable when more definitive answers will be available for geopressured development. A good summary of the subject may be found in the March 28, 1980 issue of ***Science***.[7-22]

It seems unlikely that geopressured sources will produce commercial quantities of natural gas within the next ten years. On the other hand, in twenty years or so, with gas prices and usage deregulated, the geopressured zones may be supplying a large share of U.S. energy. It is perhaps interesting to note that the greatest amount of energy in geopressured reservoirs is in its methane. Teller has noted[1-3] that the energy of methane contained in geothermal rock is about 100 times the energy of the hot rock itself. This is a fact that geothermal enthusiasts should ponder.

But, at temperatures of around 250°F or more and pressures above 10,000 psi, there is considerable energy in these reservoirs for producing electricity or industrial process heat.

Dr. Philip Randolph of IGT comments:[7-5] "I'd urge at this point that we stop worrying about whether we have a thousand trillion or ten thousand trillion cubic feet of geopressured gas. We know there's a ***bunch!*** But only by drilling, by developing solid engineering data and lab research are we going to solve the gut issue: How much gas can we produce, and at what price?"

Methane Hydrates

Molecular cavities in water can hold up to 15% methane maximum, while the pores in sedimentary rock that hold water are only a small portion of the rock volume. As pointed out in Chapter 4,[4-3] Hubbert assumed sedimentary rock pores to occupy 20% of the rock volume. Although some water in the rock pores may be completely replaced by natural gas, the chances are slight. So, if water in the pores contains methane, then the methane is no greater than $.15 \times .20 = .03$, or 3% of the rock volume.

An interesting situation develops in storing hydrogen. Compressed to any pressure, the amount of gaseous hydrogen which can be stored in a practical-sized tank cannot propel an automobile for a practical operating range. The situation for an airplane is much worse; it is utterly impractical to consider gaseous hydrogen in aviation. Automobiles, however, can consider metal hydrides because, curiously enough, in a given tank volume, ***more hydrogen can be stored in metal hydrides than as liquid hydrogen***. Metal hydrides, such as titanium hydride, start with only the metal in the tank; the hydride is formed when the tank is fueled with hydrogen and takes up spaces in the titanium molecular lattice. A metal hydride storage system is far too heavy for aviation.

The characteristics of methane hydrate "storage" is something like molecular storage of hydrogen in metal hydrides. Under favorable combinations of pressure and temperature, methane (natural gas, CH_4) combines with water to form a crystalline, ice-like solid, methane hydrate. There are several types, depending on the molecular arrangements. A cubic foot of methane hydrate can hold up to six times as much methane as free methane gas in the same space![7-23] Favorable conditions for methane hydrates are believed to exist under large areas in arctic regions and below the earth's oceans.

Methane hydrates are well known in the oil industry because they are encountered during the pressure release and pumping of oil wells, where methane hydrates solidify to clog valves and fittings in the plumbing. They cause similar problems in natural gas pipeline operations. Hydrates can also occur in natural oil reservoirs, where they block pores, reduce pressure, increase oil viscosity and generally make production more difficult. In that sense, methane hydrates to the petroleum industry are like carburetor ice to the pilot; the industry would be happier without them.

While methane hydrates do exist in fossil hydrocarbon deposits, another concept for their occurrance is, indeed, electrifying! There are many who feel that methane hydrates are not necessarily limited to fossil origin. There is significant reason to believe that methane hydrates were laid down as a natural consequence in the formation of the earth's crust. If so, the supply would not have been limited by the amount of prehistoric life, its deposit in natural basins, the formation of sedimentary rock, the necessity for cap rock entrapment, and all the other rather peculiar geologic circumstances which were necessary in order to provide our natural fossil fuel resources.

In particular, in the ***National Geographic*** Hodgson notes[7-5] that some Russian projects have been extracting methane hydrates and that they believe the earth may contain up to 1.7 million Tcf of accessible hydrates, enough to supply the world for 30,000 years! If only 1/100th of 1% of the potential methane hydrate supply could be made available, it could have an impact on the world's energy economy.[7-23]

But extracting methane hydrates from below the oceans or arctic regions might approach the difficulty of getting our iron from the earth's molten core. Some feel that the Russians who are enthusiastic about methane hydrates are comparable to Americans enthusiastic for a solar energy space station or colonization of Mars.

We certainly don't know enough about methane hydrates yet to form a strong bias for or against. What we do know is that, like any other source or form of energy, methane from hydrates must be able to compete directly in the energy market. Since methane from hydrates is identical to that produced by any other means, competition for methane hydrates already exists; it is the natural gas market.

Evaluations have been made of the locations for hydrate fields, the purity and type of media they form, the thermodynamic conditions within their compositions and the thermal properties of the reservoirs. Calculations were made to determine the energy required to dissociate the methane and the amount of gas recovered. The conclusion was that, if the hydrates exist in a pure enough state, they have a good potential for producing gas with a greater energy content than is needed to break down the hydrates.[7-23]

The Russian tests reported releasing up to 19 million cu.ft. a day from a well by injecting methanol. More immediate, the Russians drilled through layers of hydrates and found ". . . huge volumes of free gas trapped underneath."[7-5] It has been pointed out that penetrating the boundary zone between a hydrate layer and free gas could create a pressure drop which would cause the hydrates to melt, adding large quantities of gas to the flow. One cannot help but speculate that the Soviet gas now being offered to Western Europe may be derived partly from these sources.

Deep-Earth Methane

Deep-earth methane is not included in lists of UGR prospects. It is another, altogether and unrelated potential source of natural gas. If any deep-earth methane is being produced today, it has not been recognized as coming from that source.

Gold and Soter[7-24] consider a nonbiological source of natural gas which is volcanic in origin, clearly distinct in form from methane hydrates: "Diverse evidence leads us to believe that enormous amounts of natural gas lie deep in the earth and that if they can be tapped, there would be a source of hydrocarbon fuel that would last for thousands of years. The hypothesis that there is much gas deep in the earth also provides a unified basis for explaining a number of otherwise puzzling phenomena that either give warning of earthquakes or accompany them."

It is well known that large amounts of various gases, including methane, are released during volcanic eruptions. But the original source and composition of the gases are not known.

"The hypothesis that the earth contains much nonbiological hydrocarbon begins with the observation that hydrocarbons are the dominant carbon-containing molecules in the solar system. The universe is made mostly of hydrogen, and the evidence of cosmochemistry suggests that the earth and rest of the solar system originally condensed out of a hydrogen-saturated nebula. Most of the carbon in meteorites, which provide the best clues to the original composition of the inner planets, is in the form of complex hydrocarbons with some chemical similarity to oil tars. . . . The earth's primary atmosphere probably held most of its carbon as methane (CH_4)."

The authors[7-24] go on to present a hypothesis in which most of the earth's hydrocarbons may have originated from nonbiological sources and note, "The British chemist Sir Robert Robinson has written that — 'it cannot be too strongly emphasized that petroleum does not present the composition picture expected of modified biogenic products, and all the arguments from the constituents of ancient oils fit equally well, or better, with the concept of a primordial hydrocarbon mixture to which the bioproducts have been added.'" They favor a ". . . dual origin, with some hydrocarbons derived from buried organic sediments and a probably much larger amount added to those hydrocarbons from a stream of nonbiological methane."

Environment within the earth provides heat, pressure and catalytic conditions which, from methane, can polymerize all the products found in "fossil" hydrocarbon deposits.

The Gold-Soter hypothesis goes on to note that, of the thousands of commercial oil fields, about half the earth's known oil is contained in only 33 fields (25 in the Middle East). A theory of nonbiological hydrocarbons can explain this phenomenon which traditionally perplexes oil geologists. They note the prevalence of hydrocarbon deposits around the earth's active fault and volcanic areas, the fact that deep brines of the Red Sea contain about 1,000 times more methane than normal seawater, how leakage of methane could account for earthquake precursors and aftershocks, and many other phenomena.

Seismologists have long puzzled how earth fractures can occur at pressures and depths where rock should be completely plastic, but earthquakes have been recorded below 400 miles. The presence of deep-earth gas offers an explanation. Gas could explain other puzzling phenomena encountered with earthquakes: sheets of flame, "earthquake lights," fireballs, fiercely bubbling water, (". . . during the great Chilean earthquake of 1960 observers on the shore over a range of 450 kilometers reported that the sea appeared to be boiling."), exploding and hissing noises, visible waves rolling along alluvial ground suggesting lifting from the bedrock, tsunamis, changes in velocity of seismic waves and electrical conductivity of the ground, changes in tilt and elevation, emanation of radon gas, mud volcanoes, disturbance of water in wells before earthquakes, behavior of animals.[7-24]

"We believe that in addition to suggesting new approaches to earthquake prediction the deep-earth-gas hypothesis suggests the possibility that very large amounts of methane from internal sources have accumulated in regions where, on the basis of the conventional biological-origin theory, they would never be suspected."

The quantities of methane, carbon dioxide and other gases released by volcanic action, earthquakes and seepage could be vast. If so, or if there is a cycle of carbon dioxide release from the earth, absorption by the oceans, deposit into sediments and reformation as hydrocarbons, man's contribution to the "greenhouse effect" from carbon dioxide in the atmosphere may be trivial.

Substitute Natural Gas (SNG)

There may be valid criticism that too much space in this report is devoted to UGR, particularly sources as "far out" as methane hydrates and deep-earth methane and, correspondingly, not enough space to SNG. The reason is that almost any of the sources of UGR and particularly methane hydrates and deep-earth gas, could completely revolutionize the U.S. and the world energy picture. They could be the "completely unforseen" happenings that the IIASA study[1-6] had in mind in observing that forecasts beyond fifteen years are likely to be overturned by unexpected events. If significant developments occur in one or more of the UGR areas, the results are ***likely*** to be revolutionary.

SNG may become important but is unlikely to be revolutionary. In fact, since so much natural gas is expected to be available at various levels of market prices, SNG can participate only where it is capable of competing in price at a given location. Its sources are well known, although its price on the U.S. market must still be proven in significant production quantities.

SNG may participate in the market, but is unlikely to be influential in market pricing. As may be seen in Figure 7-5, the prospects for SNG are relatively small. In 2000, it could contribute from 7-20% of the U.S. gas supply. If gas is deregulated or if various UGR sources become competitive, the contribution of SNG would be correspondingly decreased. Stagnation in world oil prices also depresses the prospects for SNG.

The size of present U.S. energy consumption and of the U.S. natural gas market are essentially incomprehensible. It is sobering to reflect that the U.S. consumes more ***tonnage*** of natural gas now than it does of concrete each year.[7-25] Yes, that's tonnage of concrete, not just cement.

The largest U.S. SNG source in the near future will be the Great Plains Coal Gasification plant in Mercer County, North Dakota, about 75 miles northwest of Bismark, between the town of Beulah and the Garrison Reservoir.[7-26] In early 1980 its first

of two phases was projected to cost well over a billion dollars and was escalating at $100 million a year. The plant cost estimates occupied 51 volumes of text and cost a million dollars to assemble; its environmental **permit** covers an eight-foot shelf.

Its first phase will deliver 40 billion cubic feet of SNG per year, which is about one five-hundredth (0.2%) of U.S. gas consumption. Its technology is well known, being the same basic Lurgi process developed in Germany and used in the South Africa Synthetic Oil, Ltd. plant, SASOL, the largest synthetic fuel plant in the world, and likely to remain so for some time.

The Great Plains plant will recover 75 tons/day of sulfur from its low-sulfur lignite (low-grade coal) and will produce 100 tons/day of anhydrous ammonia as by-products. It will use 22,000 tons per day of lignite, a million pounds of water per hour, will occupy a site of 2000 acres, was originally planned to begin operation in 1981, is finally starting construction, and would face competition from the Alaskan gas pipeline, which has not been approved. Rapid development of tight-sand gas due to its price deregulation might have affected the decision on this plant, had the information been available earlier. Since Great Plains is tied into the utility network, its ultimate customers will pay for any cost disadvantage it suffers. Groundbreaking was held up over a year when General Motors, one of the gas subscribers, contested its product pricing structure in the courts. Incidentally, while the delay was in effect, it was said to be costing the project a million dollars a day.

So, SNG from coal will probably be a market follower, rather than a market leader. Like SASOL, it gives OPEC something to think about and it provides a base for future-generation coal gasification. But this large operation will have a negligible effect on even the natural gas market in the U.S. and it is unlikely to affect aviation in any discernible way.

SNG from biomass such as landfills, garbage, manure and sewerage is likely to contribute less on the whole than gasification of coal, lignite, peat and other unrenewable sources. But in one sense its contribution may be much more significant to aviation. Methane from landfills is on a commercial basis today and the Getty Oil Company, among others, has a subsidiary, Getty Synthetic Fuels, Inc., which specializes in installation and operation of landfill gas recovery units.[7-27]

Generally, about five million tons of sanitary landfill is needed to start a commercially-economical gas-recovery operation. By the time that amount of fill is in place, it is already producing enough methane for profitable operation and is likely to continue to produce for ten to twenty years. Refrigerators, bedsprings and other large pieces should be removed as the fill is placed but otherwise any other kind of household garbage and junk can be accommodated.

A 3-foot bucket auger drills a hole for 60-70 feet, followed by a 4" crane auger to 250-300 feet. Slotted pipe is installed, the hole is backfilled with gravel, a cap is installed, and the plant is ready to operate. Most of its operating cost is in cleaning CO_2, half of the gas volume, and the very corrosive fractions from the methane. The final product is fed directly into the natural gas network.

A plant must be designed to accept about 10% settling of the landfill per year. Landfill costs can be decreased and methane production increased by adding moisture while building the landfill. Over a half-dozen plants are operating in the U.S., with large plants planned at Chicago and Staten Island. Even so, they are also likely to be market followers, rather than market leaders. They ease the costs of the landfill operations.

But there is some interest toward aviation for these plants producing methane from landfills, sewage disposal plants, feedlots, and other biowastes. They offer an interesting potential to general aviation. Since aviation gasoline is expensive, while its distribution is becoming more spotty and costly, particularly outside the U.S., liquid methane may offer a long-term distribution solution, world-wide production, quality control, as well as a price advantage. While the SNG sources may be relatively small, they may eventually become available in many of the places that general aviation aircraft wish to go, even in undeveloped and rural areas.

Together with portable liquefaction plants at small gas wells, local SNG plants may offer the G/A pilot the quality and uniformity of fuel he would like, at advantageous prices, and at locations where he would otherwise not be likely to be accommodated. This possibility is discussed further in the next chapter.

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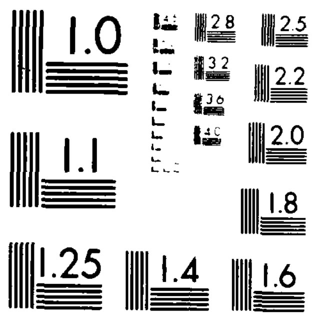

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Chapter 8

Synthetic Fuels for Aviation

Aside from discussion of the aviation fuel market in Chapter 3, this chapter addresses the future aviation fuel situation more than other chapters.

Board Room Briefing No. 8

1. As concluded in preceding chapters, this author expects conventional petroleum will be available in aviation markets at competitive prices for at least two or three decades, assuming no political or military disruption in world crude oil supply. At any time, however, a serious disruption in crude oil supply to the world or to the U.S. would disrupt the otherwise normal course of fuel prices and availability.

2. Unfortunately, the consensus from foreign affairs forecasts is that the U.S. should expect disruptions in crude oil supplies, probably as often as three times in any ten-year period. That subject is discussed in Chapter 12. In addition to the risks of world oil pricing, the need for supply reliability encourages the U.S. to reduce its dependence on foreign oil.

3. This author believes the cheapest, quickest, most effective means to reduce U.S. dependence on oil imports is by developing our natural gas potential, backing petroleum out from large segments of the oil market. But natural gas faces an array of legislative and institutional barriers which appear unlikely to be resolved. Similarly, enhanced oil recovery and other options for reducing imports, unfortunately, are also not likely to be released soon from their restraints.

4. U.S. users of petroleum-derived fuels should look to fuel substitutes, not only for protection during crude oil disruptions, but also to discourage political manipulation of world prices. Substitute or synthetic fuels, competitive with world crude oil prices, can enter the market on a large scale after huge capital investments are made.

5. It is not just difficult, it is impossible to predict if synthetic fuels will be competitive when produced in commercial quantities. The chances are good, but that answer depends more on taxes, peripheral and infrastructure costs, as well as on hard-headed cost control, than on technological developments.

6. Synthetic fuel from shale oil should become competitive and particularly attractive in aviation. But, now that the world and U.S. crude oil demand/production capacity are finely balanced in favor of the consumer, the economic prospects for synthetic fuels appear to hang within that balance.

7. There are at least two possibilities for future reductions in crude and fuel prices. First, if accelerated oil and gas exploration pays off, production within the next two to five years may be higher than producers wish. Requirements for cash flow and return on investment may prevent producers from throttling production. Second, OPEC and others could overproduce oil and reduce prices purposely to squeeze out synthetic and alternate fuel competition. The second possibility is judged unlikely by this author.

8. In the opposite direction, a disruption in crude supply or restriction of OPEC production would raise oil prices, encouraging synthetic fuel programs. This may happen due to unintentional international developments or hostilities. As discussed in Chapter 3, OPEC is not expected to voluntarily raise prices much faster than inflation.

9. Also in the direction of a price rise, U.S. and world crude oil resources may be as limited as traditional forecasts predict. If U.S. production is in its terminal decline and if world production peaks in the 1990s, then synthetic and alternative fuel developments could proceed unchallenged. While this conventional view may be the consensus today, it is losing support and this author believes synthetic fuel producers should be wary of its validity. The author does not believe either world or U.S. oil production capacity has reached its peak.

10. The long-term trend of oil production, up or down, should be confirmed during 1982, or 1983 at the latest. That is, success reports from oil and gas exploration should indicate whether future petroleum market prices will remain balanced on supply/demand economics, or whether depleting resources will boost prices upward.

11. In 1978 the Department of Defense evaluated a variety of fuel sources to replace petroleum. They discarded enhanced oil recovery as too expensive. The clear choice was jet fuel from shale oil. Resource quantity, product quality, cost, and availability time all appeared reasonable. Synthetic gas from coal could arrive before shale oil, but coal liquids will be more expensive and emerge later than shale oil. Coal liquids are better suited for gasoline; shale oil is better for jet fuel, diesel fuel and other middle distillates.

12. As directly retorted, shale oil is too viscous for pipeline transport. It contains nitrogen, metals and other impurities hostile to conventional refineries and catalysts. Most shale oil will be hydrotreated at or near the retort site. After treatment, shale oil is a high-quality feedstock which refines into excellent jet fuel.

13. For appreciable U.S. shale oil production, mining and materials-handling will require enormous investments, dwarfing the coal-mining industry. Environmental protection, infrastructure and sociological problems will be greater than for any previous human undertaking. Shale executives consider these peripheral problems greater than for primary operations. This is a sobering conclusion because none of the shale processes has demonstrated feasibility on a production scale.

14. Because of enormous investments, technical, market and other risks, as well as traditionally inconsistent U.S. energy and political policies, shale producers will approach commitments with caution and flexibility. Only one of their risks is the lack of reliable forecasts for fuel prices.

15. A healthy shale oil industry should benefit aviation greatly. Shale oil provides both quality jet fuel and supply reliability. Competition for shale-oil products may be strong from diesel and other middle-distillate customers. It may be worth a premium price to the aviation community as insurance against foreign crude oil delivery disruptions, as well as against future deterioration of jet fuel specifications.

16. Early U.S. shale oil production will almost certainly be mixed with other crudes in pipelines or otherwise blended with refinery feedstocks. If no refineries run straight shale oil, its quality advantages to aviation will be lost. U.S. aviation fuel demand is small. If shale oil production were purchased by aviation, the two industries could match well in early shale production years.

17. Aviation could benefit from a shale-oil purchase arrangement during the remaining five to fifteen years of U.S. high vulnerability to foreign crude disruptions. With a guaranteed minimum price, emerging shale interests would be protected against market reversals, stimulating earlier shale oil production. Such an arrangement would need to be consistent with USAF domestic needs.

18. The U.S. shale oil resource is so large that, if development is successful and the economics are viable, shale oil should be available at reasonable prices for "generations." Except for normal inflation, shale oil production should not experience the inexorable creeping cost of oil from progressively inaccessible locations, greater drilling depths and difficult extraction methods. Shale oil extraction begins in inaccessible locations and under unfavorable conditions. If it can compete at the beginning, it should more than hold its own while production continues and expands. Vast quantities exist in essentially comparable locations and depths.

19. Typically, up to 75% of the cost of producing shale oil, coal liquids, or other synthetics is in capital investment. So interest rates, long-term price stability and return on investment are critical to synthetic programs. Not the least, probably the greatest of the risks, is in political and tax policies. Combined with federal taxes and constraints, state and local royalties or regulations can easily trip a favorable synthetic project forecast into a catastrophic loss.

20. If competitive with petroleum, coal and other feedstocks, synthetic fuel plants are a good hedge against inflation. Once the plant is in place and producing, it will not suffer from depletion such as do all oil fields and, to a lesser extent, coal fields. Its capital costs and operating costs (except labor) should remain constant as the economy and fuel prices escalate.

The Need for Alternative Fuels

The need for synthetic fuels is predicated on rising petroleum prices and on U.S. vulnerability to disruptions in foreign crude oil deliveries.

Although there have been and will continue to be reverberations about various alternative fuels for jet aircraft, the more significant question now is how long petroleum will continue to predominate the fuel market.

In conclusion from the preceding chapters, this author believes that jet fuel from petroleum should remain available at competitive prices and in good supply for at least twenty to thirty years. There is good possibility for a much longer period. This conclusion is based on assumption that crude oil price rises during the 1970s will continue to bring new oil into the market as required at stable prices. The conclusion of this report therefore disagrees with the statistical/depletion theory and accepts the economics, supply/demand concept for future oil availability and pricing.

This conclusion does **not** depend on assumptions that: natural gas will supplant petroleum as the U.S. and world primary fuel; enhanced oil recovery will swell production appreciably; methanol will become a major world chemical and energy feedstock; methanol or methane will replace much gasoline as a ground transportation fuel; or that fuel conservation will continue to progress as much as it has during the past two years. It does not depend on any of those assumptions, but it would be reinforced if any or a combination of those possibilities should occur.

Hopefully, one or more of these eventualities will occur and the probable result will be further extension of petroleum as the primary source for jet fuel.

But, particularly during a period of fuel market stability and outlook for further market softness, ***the high probability of a surprise disruption in foreign crude oil supplies to the U.S. and to the world must not be discounted.***

Depending on the rapidity with which such a disruption is imposed, the depth of the disruption, and the time over which it prevails, impact of an expected disruption on fuel prices could be either slight or massive. As conservation further increases and fuel demand continues to decrease before the next disruption occurs, the impact of the disruption will be diminished. This is a subject of Chapter 12. If U.S. and foreign oil production also increases, as this author expects, the impact of a disruption will be further diminished.

The end to this disruptive threat will come when either: U.S. oil and gas production (new oil plus EOR, new gas plus UGR) supplants most of our current imports; U.S. synthetic fuel production supplements oil and gas to the same effect; production of other energy sources and continuing conservation combine to offset the need; combinations of the above. Because each of these components requires guesswork, while each is still actively debated, it is almost futile to speculate on the net, combined outcome.

Unfortunately, as the prospects for more oil and gas production improve, the prospects for synthetic production correspondingly recede. We may be inherently cursed with a borderline existence until U.S. combined fuel production reduces our imports to a trickle, or increased world oil and gas production relieve the entire market. None of these possibilities is likely to solve the problem for some years.

In today's "glut," the world's oil production capacity is not much greater than present demand. It is probably more than 5% excess, but not as much as 15%. The change in market climate has been dramatic as the balance shifted from −5% to +5%! So we're talking about small variations in two very large numbers, world supply and demand, over ten or more years. The two lines are nearly parallel. Can we predict how many times they will cross, and when?

It would be misleading to develop intricate forecasts or models of the situation. The more effort and the greater authority brought into a study, the more dangerous the findings are likely to be. Just going through the process generates some credibility and, the more authoritative the study, the more widely it is likely to be accepted.

While participants in such a study recognize all its frailties and use the experience only for considering alternatives, others are apt to take results literally or, in a short-fuzed situation, move ahead on its conclusions without discussing its qualifications with the original participants.

Undaunted by lack of experience, this author makes a race-track guess that U.S. ***dependence*** on oil imports should dissolve

between 1985 and 1990. Considering long experience with over-optimistic views from the same source, the author also cautions that this opinion should not influence efforts toward synthetic fuel production, filling the Strategic Petroleum Reserve, intensifying enhanced oil recovery, unshackling natural gas, increasing conservation, exploring renewable energy sources, and other efforts to diminish our dependence on imports.

On the contrary! A combination of these efforts will be needed to relieve the U.S. reversal or relaxation of these efforts could self-fulfill the crude oil disruptions that these measures may eventually eliminate.

Alternatives to Petroleum Jet Fuels

Although gasoline has been a good fuel for automobiles, jet fuel from petroleum has been an even better choice for commercial aviation. It has more virtues than detractions. If it should continue to be readily available at reasonable prices, there are few incentives for alternatives. Sizeable investments in our existing aviation fleet and equipment assures that no alternate fuel will be accepted soon, except by necessity or by offering a saving in total system costs.

Experience with foreign pricing and embargoes has shown that no fuel is a good choice if it is unavailable or expensive. Now that petroleum fuel costs are the predominant factor in airline operations, aviation should be more concerned than ever about the stability and price of its supply source.

Fortunately for commercial aviation, the Department of Defense has been concerned about the reliability of petroleum sources and about future price trends. In October 1978, the Department of Defense Shale Oil Task Force issued its report,[1-9] with the clear conclusion that shale oil is superior to other alternatives. Inflation, prices and the market balance have shifted since that time, but relative merits of the candidates considered by the Task Force have held. These candidates included Enhanced Oil Recovery, Oil Shale, Tar Sands/Heavy Oil, Coal Liquefaction, Hydrogen and Biomass.

In her letter of transmittal to the Deputy Secretary of Defense, Under Secretary for Research and Development Ruth M. Davis[1-9] advised: ". . . Department of Defense planning assumes that liquid hydrocarbon fuels will power its mobile platforms systems and equipment for the foreseeable future. . . . the Department of Defense (should) plan for an orderly transition from natural crude to synthetic fuels during the time period 1985-2010. The report also points out that shale-derived military mobility fuel is an attractive near-term alternate to natural crude oil."

Among the report's comments: "The nation's recoverable fossil energy resources are sizeable. U.S. deposits of coal and oil shale contain more recoverable hydrocarbons than the world's total proven petroleum reserves. Properly developed, our domestic fossil energy resources could support national requirements long enough to allow for the orderly development and shift to renewable energy sources."

Table 2 of the DoD report is reproduced here as Figure 8-1. It ranks the candidates listed above on the basis of location, amount of economically recoverable resource, time to reach production of 500K bbl/day (the domestic military requirement), the cost per barrel in 1978 dollars, environmental, institutional and technical considerations. At that time, 1978, petroleum crude at $18.19 per barrel was better than 25% cheaper than its nearest competitor.

Interestingly, Tertiary Recovery (Enhanced Oil Recovery, EOR), was listed at $33.50 per barrel, more than 80% above the price of conventional crude. EOR was being produced then and continues to be produced now in a semi-competitive market. Its price would necessarily be high if produced in the quantity required by DoD. EOR prices were high in spite of the fact that DoD credited EOR with a recoverable resource of 52.0 billion barrels, 75% more than the 29.5 billion it credited to conventional petroleum in the U.S.

As observed in Chapter 5, the conclusion must be that production only skims the low-production-cost cream off the top of our EOR resources. Much more potential EOR production should be realized if taxes and regulations were revised. DoD forecasts and studies are constrained as are those of all other governmental departments; assumptions and analyses ***must be made on the basis of existing legislation and budgets***. In official planning, departments may not speculate on the effects of deregulating EOR, or on other legislative changes.

It is interesting that the DoD report found hydrogen the cheapest fuel next to conventional petroleum. The price reported is for hydrogen produced from coal and the cost of $22.00/BBL is based on equivalent Btu content. Hydrogen is credited with being available worldwide, an unlimited resource having minor environmental effects, undetermined institutional problems, but major technical obstacles. A significant disadvantage would be that the 500K bbl/day equivalent production would not be available until 1995.

Liquid hydrogen has the very favorable characteristic of containing 51,000 Btu/lb, compared to 18,400 Btu/lb for Jet A. But its density is so low that it contains only 29,600 Btu per gallon, less than a quarter of the 135,000 Btus contained in a gallon of Jet A. On the basis of unacceptably low density, DoD eliminated hydrogen from further consideration. If its density were not so low, they also would have considered as deterrents its required low temperature, −423°F, and its possible hazard in combat.

It must be expected that each individual and organization which compares costs or prices of various fuels will use different assumptions and inputs in their analysis. Some of the analyses become highly controversial, particularly when forecasting future economics or other conditions. Comparisons are often useful, however, particularly if their assumptions are considered consistent with the petroleum market. That judgment, too, may be in the eye of the beholder.

The author feels the significant question is less how fuel prices compare on the current market, but when each fuel may reach a competitive price status. Such a question requires forecasting so many market factors that it virtually defies analysis. Some have observed that many conclusions about fuel cannot concern our generation because none of us will live to see if the forecasts are correct. While the statement should not be taken literally, it does mean that laboriously derived comparisons are probably no better than ball-park guesses. Before events combine to bring in some candidate fuels, conditions are likely to be entirely different than when the assumptions were made.

With that spirit in mind, this report does not pursue detailed comparisons of alternative energy price forecasts. The DoD comparison[1-9] was simple but authoritative at its time and, comparatively, is probably just as valid now or for some time in the future. An additional comparison was prepared in an extensive study by Exxon Research and Engineering Company for the Department of Energy in 1980.[8-1] A comparison derived from their more pertinent options is shown in Figure 8-2. As may be seen by inspection, the range of prices for natural gas is not as wide as those that actually exist today (given in Chapter 7), due to U.S. price restrictions. But that is not a criticism. Exxon's data are more a representation of what gas prices ***should*** be.

A further comparison of fuels directly applicable to aviation is given by Boeing in Fig. 8-3.[8-2] Liquid hydrogen enthusiasts may complain that costs for that product are shown too high. If

Figure 8-1

Table 2

Alternate Energy Sources

SOURCE	LOCATION	ECONOMICALLY RECOVERABLE 10^9 BBLS.	TIME TO 500K BBL/DAY	JET FUEL COST $/BBL. FY 78	ENVIRONMENTAL	INSTITUTIONAL	TECHNICAL
1 PETROLEUM		547.8	–	18.19	–	–	–
A) CONVENTIONAL	WORLD U.S.	29.5 (5.4%)					
B) TERTIARY RECOVERY	U.S.	52.0	1983	33.50	MINOR	MODERATE	MINOR
2 ALTERNATIVE LIQUID FUELS A) OIL SHALE	WORLD U.S.	UNDETERMINED 80-200	1989	23.00	MAJOR	MAJOR	MINOR
B) TAR SANDS/HEAVY OIL	WORLD U.S.	UNDETERMINED 2.5-5.5	1989	23.00	MODERATE	MAJOR	MINOR
C) COAL (LIQUEFACTION)	WORLD U.S.	2406 657 (27.3%)	2000	33.00	MAJOR	MAJOR	MAJOR
D) HYDROGEN	WORLDWIDE	UNLIMITED	1995	22.00	MINOR	UNDETERMINED	MAJOR
E) BIOMASS	WORLD U.S.	UNDETERMINED 0.8/YR.	1995	25.00	MINOR	MODERATE	MAJOR

MINOR - PROBABLY EASILY OVERCOME
MODERATE - SOME UNCERTAINTY; NEEDS ATTENTION
MAJOR - WILL PREVENT SUCCESS OF PROGRAM UNLESS SOLVED; WILL REQUIRE SIGNIFICANT EFFORT TO OVERCOME

SOURCE: DoD ESTIMATES

derived from natural gas, the price should be lower. As will be seen, some industrial processes promise competitive prices. New industrial developments, such as possible magnetic liquefaction of hydrogen, could make dramatic changes, depending on how much credence one is willing to give them.

Liquid methane enthusiasts (on the basis of Chapter 7, probably including this author) will ask why methane costs are given for manufacture from coal when methane is already available from natural gas pipelines at lower prices? Answer — earlier studies were all based on fuels derived from coal for directly comparable conditions; later studies have duplicated those conditions to remain comparable.

But these are arguments in detail, not in principle. Petroleum is the basis for our current market and all candidates must compete on that basis. If and when each of the candidates becomes competitive, it will successfully enter the market. The possibilities for special or local conditions, or for future developments are endless. Each supplier must continuously evaluate his competitive position. The consumer need be concerned only with the possibility that his fuel price may change, that its supply may be curtailed, or that a cheaper product may enter the market.

Audaciously summing it up: ***Except for disruptions in foreign crude deliveries to the U.S. or to its trading partners, the world petroleum market is likely to remain stable or soft for a number of years.*** In the short term, this conclusion depends on Saudi Arabia's continuing to produce oil at a rate to satisfy the world demand margin. In the longer run, it depends on whether U.S. and world oil resource depletion follow the statistical or the economic forecasts. If statistical, prices should probably begin to rise again above inflation in about five years and then accelerate upward. Synthetic production, beginning largely from shale for middle-distillate fuels and from coal for gaseous fuels, gasoline and methanol, should by then enter at a competitive level and petroleum would cease to drive the market price.

An alternative version of this scenario is that synthetic production could begin to enter ***initially*** at competitive prices and that its entry would therefore prevent any upward trend of the liquid-fuel market.

If oil depletion is not imminent, as the economist-forecasters contend, oil prices should remain steady (relative to inflation) for at least another twenty or thirty years, perhaps longer. Synthetics could compete in this market, but only if their production costs remain reasonable. Whether they are in or out of the market may be immaterial to this scenario. Under those circumstances, petroleum could meet the demand without synthetic assistance.

A corollary to this scenario would be the significant ascendancy of natural gas suggested in Chapter 7, or perhaps of EOR as discussed in Chapter 5. Either could effectively reduce demand for crude oil, maintain crude at stable prices, and stretch out the supply over many decades, virtually regardless of the size of the crude resource.

If these considerations are equally valid (and no one suggests they are), the probability for steady crude oil prices would be four to one. The one probability that they rise on an accelerated curve, as has been the consensus until recently, requires that U.S. oil production passed its peak in 1970 and that world production will decline from the mid-1990s. That may occur only if ***none*** of the following four transpires: (1) oil production exceeds the statistical forecast; (2) EOR production is encouraged; (3) synthetics are brought in at competitive prices; (4) natural gas production departs from the statistical pattern for oil.

This author believes the probability strongly favors a stable world oil market for: 20-40 years based on (1) or (2),above; 200-X years based on (3); or 100-X years based on (4). In case of (4), natural gas exploitation, world energy prices could drop to a lower level.

Shale Oil

From the foregoing discussion, production of U.S. shale oil at competitive prices appears to be a question of time. Some apparently think that time may be far removed now.[8-4] But if petroleum production is already in its latter stages, shale oil production may be past due, because of the lead time required.

If crude oil will be available at competitive prices for 20-30 or up to 100 years or more, present shale-oil efforts will proceed only if they can compete in about the present range of oil prices,

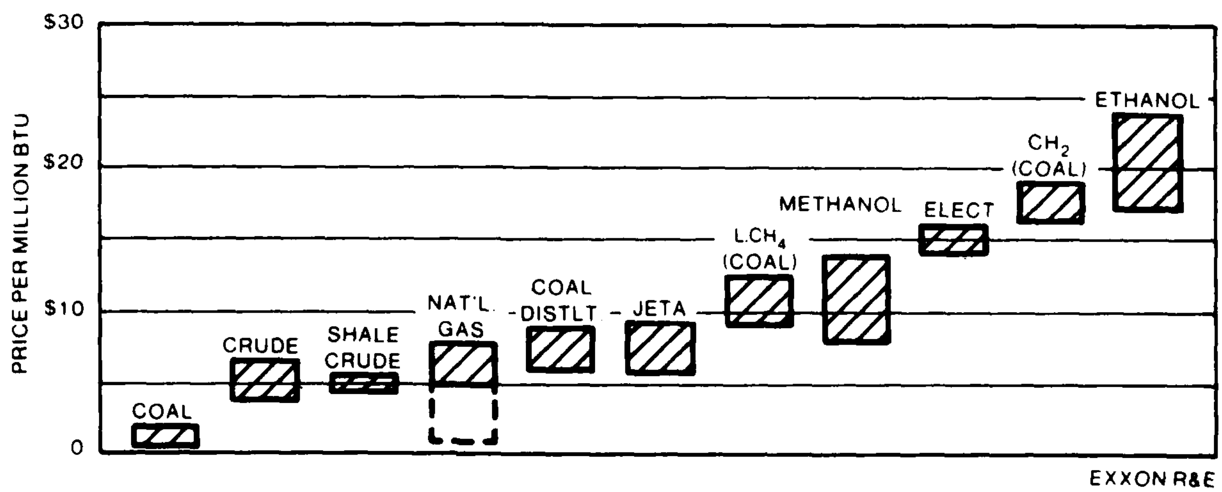

Figure 8-2

Delivered Costs of Fuels
$ per Million BTUs (1980)

escalated by inflation. As has been discussed, that price range will be a function of many things such as resource accessibility, capital investment, interest rates, water availability, environmental costs, mining and retorting efficiency and costs, infrastructure and support costs, regulations, royalties, taxes, and so on.

Shale costs may be close to the price margin at present. Some shale producers are now pessimistic; Exxon has taken its loss and withdrawn, at least for some time. John K. McKinley, Chairman of Texaco,[2-5] recently remarked that, with crude oil prices now expected to remain soft, he believes that significant development of U.S. synfuel operations will not occur until the turn of the century.

If the oil market continues soft, it may be almost immaterial to market prices whether synthetic production proceeds or not, although its psychological effect could be helpful. Produced into Jet A however, shale could provide aviation with insurance against disruptions in foreign crude oil deliveries. Aviation users should remain alert to both market prices and the possibility of disruption; probably nobody will be able to predict when the next disruption will occur.

Shale Oil Resources

Shale oil resources are much easier to assess than either natural gas or oil, even easier than coal. The geological structure is simpler, more extensive, and can be assayed with fewer test samples. Like oil and gas, shale was laid down in sediments which hardened into rock, but the material did not migrate and did not require a cap rock to remain entrapped. So a lot of the complications and unknowns about liquid and gaseous resources simply do not pertain to shale.

Shale deposits extend, essentially uninterrupted, for tens of miles. Layers are continuous and consistent in quality. Faults and fractures may affect mining or retorting techniques, but have not permitted the material to escape. Like oil remaining in a field which has already been produced, there is no doubt of its presence.

And all agree the quantity is vast. Its physical quantity is well established, to reasonable accuracy. The primary question is how much of that can be produced at different price levels. Since no shale oil has yet been produced in real market quantities, that question will remain unanswered for several years.

"Next to coal, oil shale is the nation's largest fossil fuel resource. Oil shale is neither rock nor shale. It is a fine-grained rock called marlstone that contains varying amounts of a brown to dark gray organic material called kerogen. When heated to about 900 degrees F, the kerogen reacts to form synthetic oil and gas . . ."[8-6] In the Colorado Green River Formation, deposits contain 25 gallons or more of shale oil per ton of rock. "Two tons of shale — about the volume of an office desk — would yield more than a barrel of oil."

The total amount of shale oil in the Colorado-Wyoming-Utah area known as the Green River Formation is generally agreed to be about 1.8 trillion barrels. Exxon estimates the ***high-grade resource only*** at 2 trillion barrels of oil equivalent (BOE), as compared to the world's ***remaining*** confirmed oil reserve of 250 billion bbl, or eight times as much oil in the rich part of the Green River than the remaining world oil resource! (The eventual world oil resource may be larger than assumed here).

"Shale formations also exist in the East, in roughly a triangular region from Michigan to western Pennsylvania to Mississippi. This area, known as the Devonian and Mississippian

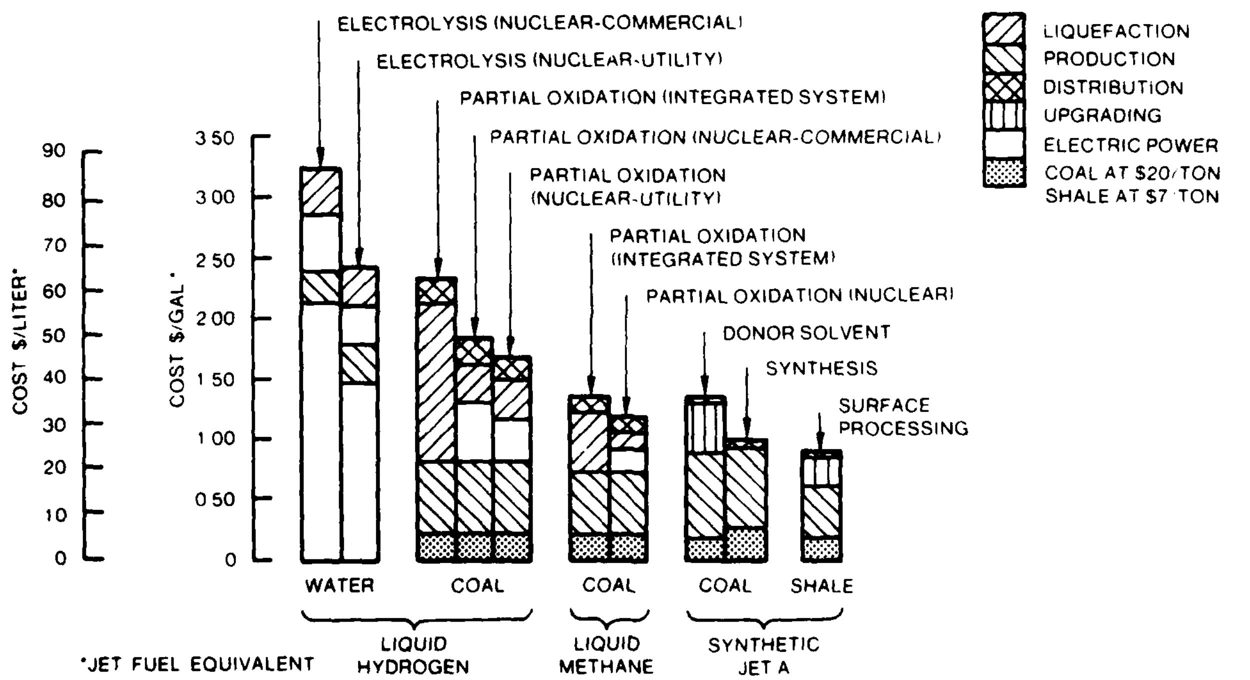

Figure 8-3
Alternative Fuel Cost

1979 Dollars

deposits, is predominately of lower grade — less than 15 gallons per ton —and gasification is considered the most applicable technology. The potential yield, however, is significant. Some three trillion barrels of oil equivalent might be contained in these deposits, although uncertainties still exist as to the amount that is economically recoverable."[8-6] Other estimates of eastern shale run as high as 40 trillion barrels.[8-7]

In comparison with this minimum potential 4.8 trillion barrels for both the rich Green River and eastern shale, recall from Chapter 4 that Hubbert originally placed the U.S. recoverable total petroleum reserve at 170 billion barrels, since revised upward to over 200 billion by the statistical method.

Our eastern shale is seldom mentioned; it is the Rocky Mountain deposits which receive most of the attention, because of their higher yield. From very sketchy exploration, there may be another trillion barrels of shale oil in Alaska.

So there is no contest — estimates of recoverable U.S. shale oil run from 30 to over 3,000 times the statistical estimate of original U.S. oil in place. Whenever U.S. shale production is able to compete with world crude oil prices, our shale era should be much longer than our oil era, stretching on ad infinitum.

In 1979 the DOE[8-6] estimated almost 40% of the Green River shale would be recoverable, or about 600-800 billion barrels, more shale oil than the DoD estimated for world-wide conventional oil reserves, and this is only the western resource. DoD put the recoverable shale resource at only 80-200 billion barrels when they selected shale oil. The quantity is not too important; it's more than plenty for several generations.

Shale Oil Production

Exxon forecasted before the recent market slack[8-8] and their withdrawal from shale operations, that the U.S. might achieve 750,000 bpd synthetic fuel production (from both shale and coal) by 1990, 4-6 million bpd by 2000, and 15 million bpd by 2015. That is, by 2000 we could have been independent of foreign crude with synthetic oil alone and, by 2015, shale oil could have replaced much of U.S. domestic crude, possibly all of it. Other forecasts were more conservative. Now with Exxon's withdrawal and crude oil price stability or recession, that level will not be achieved.

But the Exxon forecasts are pertinent to consider the impact of future possibilities. At a 2 million bpd production level, the materials-moving task is comparable to digging a new Panama Canal each year. Environmental problems begin to get thorny around that level, while water supply problems also enter into the question. Some have estimated that a 2 million bpd production rate would absorb all the world's mining and earth-moving equipment production capacity, suggesting intolerable price rises in that market.

The size of the task is almost incomprehensible. One shale operator has commented that, if we weren't concerned about environmental problems or early return on investment, the job could best be done by working from the surface, rather than by using deep-mining techniques. In an area about 30x30 miles, or approximately 1000 sq.mi., from the top of the mesas at about 8000-foot altitude, the overburden would be removed to a depth of 300 feet. Capital investment for that operation would be immense. From that depth to about 1000 feet below the original mesas, the operation would be self-supporting economically, as the lower-grade ore is removed. At about the 1000 ft. level, the so-called "Mahogany zone" (from its color), or richest layer, profits would begin to roll in.

Present production schemes break into two broad categories: (1) Mining the rock by conventional means, crushing and retorting it at the surface. (2) Rubblizing the rock underground by explosives, firing and retorting it in place, ***in situ***, and pumping the resulting oil to the surface.

According to DOE, "A room-and-pillar method is believed to be the most practical mining system. In this technique, interconnecting tunnels are mined leaving a checkerboard pattern of pillars. As a second step, once the initial production is completed, some of the remaining pillars are mined. Initial underground mining of oil shale will probably be confined to the 30-90 foot thickness of 30 gal/ton and richer oil shale in the Mahogany zone of the Green River Formation."

"Surface mining techniques such as open pit and strip mining may also be useful in areas containing significant oil shale deposits. Generally, in mining oil shale by surface techniques, both overburden and oil shale will require drilling and blasting and use of large 'jumbo' rotary drills. Large shovels, draglines and trucks will be required to move the blasted material to the disposal area or to crushers from which ores or wastes would be conveyed to either a dump or processing area."[8-6] Retorting at the surface is more or less conventional, although the scale is giant. Just for a feel, retorts are about 400 feet tall; the Washington Monument is about 550 feet.

Colony was a joint project of Exxon and The Oil Shale Corporation (Tosco) which is still a good example and was targeted to produce at a rate of 47,000 BPD of synthetic oil in 1986. Bear in mind that 47,000 BPD would represent the throughput of a small refinery; an average medium refinery processes 100,000 BPD, while the Baton Rouge Exxon refinery is in the 500,000 BPD category.

Instead of sinking a shaft from the top of the mesa, Colony built up an earthen mine bench from the Parachute Creek canyon floor to the Mahogany zone level, where the thickness of the layer is about 60 feet and the ore yields a little over 34 gallons per ton. Working from horizontal portals and using 85-ton trucks, the mine would have been worked in the conventional room-and-pillar configuration. The ore was to be crushed to -9" size at the mine bench level in a 6x9' gyrator crusher and then transported by a 5000' conveyor belt to the top of the mesa. There ten secondary impactor crushers would reduce the ore to -1/2", whence it would enter six Tosco retorts, each of the 400'-ft. category. Each retort would process 11,000 TPD of ore, for a total of 66,000 tons, yielding the 47,000 barrels of oil.

Along with the ore, ceramic balls heated to 1200°F were to be introduced into the retorts, heating the ore to 900°F. Its kerogen would vaporize and be separated from the spent shale; with kerogen removed, the rock reduces to a fine powder.

Some press reports have spread the incorrect concept that spent shale expands in this process. It does not, but the fine powder cannot be re-packed into the original space simply because the parent rock was quite dense.

The heated, spent shale would be used to produce steam, then deposited in canyons and planted with native vegetation. Most of the water requirements would be for land restoration, since the shale process reuses water in condensing oil vapor. About 3-4 barrels of water were expected to be required for each barrel of oil produced. Water was to be pumped in from the Colorado River at the mouth of Parachute Creek, where the town of Parachute Creek is located and the support community of Battlement Mesa was being built.

Oil shale vapors from the retorts would have been condensed, fractionated, and upgraded by hydrotreating for pipelining to a conventional refinery.

Colony had been proceeding toward bringing the entire plant on stream in late 1983, well ahead of the 1986 target. Capital cost at the 47,000 BPD production level was supposed be $3-4 billion, which did not include the cost of Battlement Mesa — a

community of about 25,000 people — and other infrastructure commitments. Colony was assisting local organizations with interest-free loans for schools, a fire station and other necessities. It is not known which parts of the project were judged to have exceeded their cost estimates, but ***Newsweek*** reported the estimated cost of the project had risen to $6 billion.[8-4] Anyway it's sliced, that comes out close to $130,000/barrel/day production capacity.

The ***in situ*** process seeks to reduce mining and restoration costs by retorting most of the ore in place. It is also expected to be applicable to lower-grade ores. No single version of the concept is applicable to all types of ores and formations; each is fairly well-tailored to its specific site.

"In general, the variations can be grouped under two broad categories: (1) modified in situ, where a void is created by mining or leaching; and (2) true in situ, where the zone is rubblized and retorted without creating a man-made void."

"Vertical modified in situ techniques are believed to offer the most promise for early development and are especially attractive for deeper and very thick (more than 300-feet) deposits. In October 1977 DOE signed a contract with Occidental Petroleum Corporation to develop a vertical in situ process at Occidental's Logan Wash site in Garfield County, Colorado. In Occidental's process, about 20 percent of the shale is mined to form an underground compartment. Then surrounding shale is broken up and expanded by explosives to create a kind of underground chimney full of rubblized shale. From the top of the chimney, a small amount of oil is ignited and the retorting begins. Combustion of the chimney moves slowly downward — typically 1-2 feet per day — and the heavy oil produced flows by gravity to the bottom where it is collected and pumped to the surface."[8-6]

"A horizontal true in situ technique being developed by DOE and the Geokinetics Oil Shale Group, is currently applicable only to very shallow depth formations (less than 100 feet of overburden). Conventional mining is not used. Instead explosives expand and break up a bed of shale lifting the surface of the ground noticeably."

In situ techniques must deal with the problem of effective rubblization and combustion. The Colony project expected to control its retorting process by carefully grading the crushed ore and heating with ceramic balls. In fact, projects that heat ore with gases or burn ore in controlled retorts above ground often find that combustion moves through channels, rather than uniformly through the rubble. This problem of channelized combustion has received high-level attention and a sophisticated technology has been developed on the subject. At least one mathematical model[8-9] can incorporate various flows and counterflows of gases injected at various locations and at different rates, temperatures and densities; it considers chemical reactions, as well as mechanical and thermodynamic effects.

The in situ processes encounter great difficulty in obtaining uniform rubblization with explosives. Trial retorting in place has frequently produced disappointing yields. But those processes are proceeding and are are likewise being analyzed with impressive talent. Reference (8-10) is concerned with rubblization such as the Occidental process, while (8-11) explores the use of uniformly-spaced vertical holes bored into a shallow formation, retorting with a flame front propagated down the holes.

There is a large variety of projects and technologies being used. Reference (8-12) summarizes the location, process, permits, impacts, management and financing for almost thirty separate projects in both the western and eastern United States. Since its release, however, Occidental and others have slowed their operations, while Exxon has canceled completely.

As has been mentioned, capital costs for shale oil projects and, for that matter, all synthetic fuel projects, are great. At the Georgetown CSIS forum[1-3] in October, 1981, this author presented investment costs estimated by Exxon at $53,000/BPD, based on the ultimate possibility of 15 million BPD U.S. production rate at an estimated cost of $800 billion in 1980 dollars, or approximately $3 trillion "as spent." At the same time, the cost of $70,000 BPD production capacity was derived from Chevron's startup costs of $7 billion for 100,000 BPD.

When these cost estimates were presented, there was an immediate chorus of comments from the group, which included representatives from both Exxon and Chevron, that these costs were much too low. The verbal consensus was that costs then (October, 1981) could be no lower than $100,000 per barrel per day capacity.

Costs may have risen further, as indicated by the Colony Project; they no doubt contribute to the recent decline in shale activity. Some think that rising costs have been far more instrumental than softness of the crude oil market.

While oil prices at that time had been escalating faster than inflation, the machinery, materials and personnel for oil development, and competitive efforts such as shale development, were escalating even faster. As Paul Petzrick of DOE concluded the discussion, "What these numbers are really proving to me is that there aren't any smart people in the shale business because smart people would have built their plants with pre-1969 dollars, at $8-10,000 *per daily barrel and sold the oil at post*-1973 prices. Just in the five years I've been working on it, the price tag has probably gone up from about $15-20,000 to, as you say, over $100,000 per daily barrel. . . . I tell my people that during the time of their coffee break, the interest on one of the $3 billion plants could pay the annual salaries for everybody in the office. . . . In five years, we may have to do it for $300,000 per daily barrel, but we should go ahead now at $100,000."

To illustrate the difference in capital costs between oil and synthetics, onshore Alaska wells cost up to $20,000 per daily barrel, with North Sea wells a little higher at $10-35,000. Costs of Lower 48 wells may be less than half and, in fields like Saudi Arabia, the capital costs are so low compared to their high production rates that definitions of the accounting procedure have more effect than the cost of the well. Capital costs are ridiculously low for some oil being produced today. Capital costs for all synthetic fuel projects are very high.

The world price of oil is obviously not based on cost and demand, but is artificially maintained by reducing production.

As has been mentioned, costs of the synthetic operations won't be known until some of the projects actually achieve stabilized production output rates. That will require at least two years in normal operation, more with deceleration. Costs will vary due to location, geology, production methods, rates of production, infrastructure, environmental requirements, financial plans, access to water, and local taxes and regulations. The operators seem to be equally concerned with these variables now as with the outlook for crude oil prices.

Managers and financiers have been watching the market closely. More and more articles have appeared like that in ***The Wall Street Journal*** of December, 1981.[1-13] "On the Back Burner: Synfuel Plans Delayed by Stable Oil Prices and Plentiful Supplies." That article observed that the oil market slowdown has divided analysts, that caution is building and that the Synthetic Fuels Corporation is taking a middle road. "'It's pretty much agreed that synthetic-fuels development is going to go ahead a lot slower than we had anticipated,' says Michael Koleda, president of the National Council on Synthetic Fuels

Production, a trade group." A spokesman from Data Resources, Inc. is quoted as believing that the market is being artificially depressed by the Saudis.

The Georgetown CSIS meeting did not agree with that view, nor did the sense of the DoD meeting on Mobility Fuels Supply and National Security in February, 1981. While the present "glut" had not become fully evident at those times, both gatherings indicated that OPEC was much more concerned with basic market forces. Individual OPEC members are even more concerned with their specific income requirements. Individuals in the shale industry expressed similar opinions before the oil market decline; they do not believe OPEC and the Saudis are really concerned about synthetics. Maybe in five to ten years, but not now.

Returning to the *WSJ* article, it noted an opposite view from Fred Singer, professor of environmental sciences at the University of Virginia. "If the U.S. moves too quickly to build a large domestic synfuels industry, he says, the result will be a tremendous surplus of oil. That, he says, would sharply depress world oil prices, which would leave the synthetic-fuel projects economically stranded. By the late 1980s, Prof. Singer says, the synfuels industry would be exerting pressure on Washington for protection from 'cheap Arab oil.'"[8-13]

This author does not dispute that the world may develop a significant surplus of oil, particularly if assisted by high production of natural gas or EOR. Also, the synthetic industry may seek price protection at some time in the future. But it is believed here that these situations cannot be influenced significantly, other than psychologically, by the rate of U.S. synthetic fuel production until after 2000. Of course, the more investment the U.S. synfuel producers make, the more they will protest a drop in world prices. But their contribution to the world fuel market or even to the U.S. fuel market, will be nearly trivial for some time.

A reflection on the investment dollars required per barrel-day of production capacity may indicate that the ***capital required will not be raised without tacit agreement of OPEC and Saudi Arabia.*** This statement is admittedly facetious, but may be more true than we would like.

The *WSJ* article went on to report that the White House appears undeterred by price developments and is giving the SFC full support. That policy was reconfirmed by DOE Deputy Secretary Kenneth Davis on Feb. 17, 1982[8-14] and U.S. Vice President George Bush the following day.[8-15] At the same meeting, however, Dr. Bernard S. Lee, President of IGT, noted[8-16] Sheik Zaki Yamani of Saudi Arabia recently remarked that the West, if forced to develop alternatives, could do so in about seven years. Dr. Lee's own comment was that it will take two or three decades for the U.S. to achieve real production capacity with synthetics.

Dr. Lee also noted an OECD study has concluded that development of alternative sources and additional expenditures for conservation would cost OECD countries \$1.8T less over a forty-year period than the cost of the foreign oil imports these investments would displace. ". . . the OECD study does not take into account the so-called indirect costs; that is, their effects on employment, inflation, and national security." IGT concluded the real cost to the US economy of a barrel of imported oil is ". . . on the order of \$80-100."[8-16]

Coal Synthetics, Lignite and Peat

While there is much conjecture about synthetic production processes, future potential, forecasts of capital costs and such, there appears to be no argument that oil shale will produce middle-distillate fuels more cheaply than will coal.

Coal is well suited for production of gaseous fuels. Coal gasification is competitive with natural gas in some locations now and, unless natural gas becomes much more available at reasonable prices (which this author expects), coal gasification should become more prevalent in the U.S. (which the author does not expect). At higher cost, coal can be directly synthesized into liquids. The processes yield a liquid fuel with high aromatics and octane characteristics, good for gasoline but not attactive for aircraft jet powerplants or for diesel fuel. It should be noted, however, that with additional hydrotreatment, this same coal product can be converted into quality jet fuel.

By comparison, raw shale oil is viscous, heavy in nitrogen, metals and other impurities. But, when hydrotreated to remove these impurities and, more importantly to permit the shale product to be pipelined and processed in a conventional refinery, shale oil becomes an excellent feedstock for jet fuel. Shale oil refining is discussed further in the next section of this chapter.

So, as is typical of fuel matters, the issue resolves to cost and price. Shale oil must be hydrotreated for handling, whereupon it assumes excellent characteristics. Even with this sophisticated processing, it currently yields a lower-priced product than does coal. If coal liquids are further processed to jet fuel standards, their cost is raised further.

It appears that there is no chemical, energy or economic avenue which is likely to render coal a preferable source for jet fuel. However, future development in catalysts is expected to permit synthesis of essentially any liquids, including jet fuel, from gasified coal. While the process costs should reduce, the thermodynamic energy cost of the processes still favor shale over coal for jet fuels.

Under unique circumstances, some jet fuel will no doubt be produced from coal at some specific locations in the world. But those circumstances will exist where shale oil is not available.

We may expect coal, then to contribute to jet fuel production outside the U.S. and to the future of aviation gasoline inside the U.S. Further discussion of coal synthesis is deferred to Volume 2.

The comments on coal apply as well to lignite and peat. Lignite is a sub-bituminous coal with higher ash content which, due to its lower ratio of energy content to weight, generally is not shipped. In discussing geopressured gas resources with the Louisiana Department of Natural Resources, they speculated that lignite in the Gulf Coast region may be the more important. Already Texas, which is as well-endowed with natural gas as any state, is producing most of its electrical and industrial power with local lignite. Louisiana expects to increase its use of local lignite. Their natural gas can be exported more profitably.

Because of little interest in the past, U.S. peat resources have not been carefully surveyed. But U.S. peat lands are estimated to cover over 50 million acres and to contain the energy equivalent of about 240 billion barrels of oil.[8-17] That is far less energy than represented by U.S. coal, natural gas or shale, ***but it is more energy than the statistical forecasters credit to total recoverable U.S. oil resources.*** Peat, therefore, should not be ignored.

Peat is biomass which has already been grown. Although it is found in all 50 states, the richest deposits are in Alaska, Minnesota, Michigan, Florida, Wisconsin, Louisiana, North Carolina and Maine. Its greatest handicap is that there is no peat industry and relatively little peat technology in the U.S.

Since lignite is close to the surface and peat is on the surface, mining or harvesting of either does not require the same capital costs as for coal or shale. Handling and, in the case of peat, harvesting and dewatering costs are important and may be difficult to forecast in large scale production. As with shale, when

peat operations are scaled up to mammoth size, there is no experience basis for the costs.

In the spectrum going down from hard anthracite coal, through bituminous, sub-bituminous, brown coal, lignite and finally peat, peat has obviously been laid down the least amount of geologic time. It is correspondingly the most volatile of these resources and contains, generally, a higher ratio of hydrogen to carbon. It is therefore more reactive and is more easily converted to gas.

Peat contains about 60% more volatile matter by weight and has 25% less heating value than lignite. Peat can be used directly as a low-sulfur solid fuel in boilers, with an environmental advantage over coal combustion. More application should be found in conversion to synthetic gaseous or liquid fuels. Peat is well suited for conversion to methanol, which may displace petroleum from the automotive market. It is wierd to conjecture that peat may be more suitable for conversion to aviation fuels than coal. The old joke, "Why did the Irish SST crash? It ra. out of peat!" could prove a boomerang.

Joking aside, peat deserves serious consideration. Peat technology is surprisingly well-developed. But industrial application experience is lacking. Other than direct combustion, the one place in the world where it is being synthesized is at the Sasol plant in South Africa. The standard Lurgi process is used. Along with coal and lignite, peat is reviewed in more depth in Volume 2.

Here it is appropriate to conclude with remarks from a Canadian source. "It seems that peat will stand or fall by this: whether wet mined peat bogs can be rehabilitated to serve as biomass farms in Canada's central and northern regions, and whether they do or do not cause any severe ecological imbalance in the process of being mined. If forests can be grown on mined-out bogs, they would help somewhat to mitigate the greenhouse effect resulting from the use of peat and other fuels as energy resource."(8.18) The question of ecology appears to be the greatest obstacle in peat resource development.

Refining Shale Oil to Jet Fuel

While jet fuel has not been refined from U.S. shale oil in production quantities, several thousand gallons have been refined in pilot plants and the experience has been most encouraging. Further, process analyses and plant designs have been made for full-scale operations. There appears to be no significant unknown or barrier at this point and, as soon as shale crude oil becomes available in quantity, refining should be able to proceed successfully and relatively economically.

If shale oil can be mined, retorted and upgraded (by hydrotreating) at costs comparable to high-grade crude oil, we have every reason to expect that jet fuel will be produced from shale oil at competitive prices. The resulting jet fuel should be of high quality, well within existing fuel specifications, and with an unusually desirable low content of aromatics, nitrogen, arsenic, iron, sulfur, oxygen and other impurities.

Jet fuel from shale appears to suffer only one disadvantage relative to jet fuel from petroleum, and that disadvantage will be common to all fuels, including those from heavy petroleum crude, which are heavily hydroprocessed. Heavy hydroprocessing reduces the lubricity of any fuel. Synthetic jet fuel from shale, in fact, synthetic crude from shale, must undergo heavy hydroprocessing.

The raw shale oil will be hydroprocessed, usually at the mine site, to reduce its viscosity for pipelining. If hauled by truck, tank car or barge, it would still be heavily pre-processed before introduction to a conventional ref ry. Its high tent of metals, nitrogen and other impurities would poison the refinery's present catalysts and otherwise degrade operations. Or, if special refineries are eventually constructed at the shale production fields to produce finished products directly from the raw retorted oil, that refining process will also include hydroprocessing. With proper selection of the catalyst, it is now possible to process and refine in one plant.

Heavy hydroprocessing appears to be the direction of the future for jet fuel, whether from increasingly heavier natural crude oil, particularly if from tar sands, from shale, or from coal, lignite, peat, or biomass. Fuels produced from these sources will characteristically have low lubricity and additives must be introduced to the fuels to lubricate pumps, valves and other components.

In one sense this is a minor point. There is no reason to believe that suitable additives are either difficult or expensive; they are not. ***But present fuel specifications, having been developed universally for fuels produced from light petroleum crude, include no requirement for lubricity.*** This is important only to the extent that it should not be overlooked. It may be desirable in the future to add a lubricity requirement for all synthetics, if not for all fuels.

Commercial jet aviation is most fortunate in that the DoD has led the way with a relatively small, but comprehensive, effective, and successful shale fuel refining program. Otherwise, it is difficult to imagine how the aviation industry and the shale industry could have gotten together so effectively and within a reasonable cost framework. Through the Air Force program (acting as agent for the Department of Defense), shale oil is ready for processing into jet fuel from the standpoint of technology, production development, and economics, as soon as the crude becomes available.

Planning was initiated by USAF Chief of Staff Gen. Lew Allen, Jr. in 1977. First funding was provided in FY 1979. Following usual small study and experimental projects, the program culminated with a USAF-funded test in which three different refining operators developed independent processes and pilot plants for refining 1000-barrel batches of shale oil into jet fuel. While the projects varied in detail, each was successful in its processing, in its product slates and in its projected production costs.

The Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson AFB, held comprehensive review meetings for all interested parties, military, commmercial and academic, November 19-20, 1980 and November 17-18 1981. At these meetings, Air Force laboratory personnel and each of the contractors, presented comprehensive and detailed reports. Printed proceedings from the symposia are available, as well as individual papers and much additional material not presented at the conferences.

In a nutshell, the program reports: Shale oil must be pretreated to protect refinery catalysts, although one contractor successfully demonstrated single-stage pre-hydrocracking at the refinery in place of pre-treatment. Treated shale oil yields a high-quality jet fuel with generous yield from a barrel of crude shale. As compared to 15-25% jet fuel yield from the typical barrel of petroleum crude, shale oil typically yields around 75% of the barrel into Jet A and B. With additional hydrotreatment at a cost increment of about $1 per barrel (about 2.5 cents per gallon), the shale oil can be converted 100% to jet fuel, combined Jet A and B. Interestingly, this volume yield may be slightly greater than the original barrel because of hydrogen added.

In the earlier of the two seminars, using a June 1980 estimate of $25/bbl for crude shale oil, the finished jet fuel was estimated at $35/bbl, or about 85 cents per gallon. At the second meeting, when details had been explored in more depth and in more directions, it was pointed out that projected costs are considered to be reliable within about 25%. Costs are so site-specific for the mine, pre-processing and refinery facilities, that closer cost estimates require these details should now be incorporated. Financing, depreciation, taxes and local inputs all enter into the 25% unknown tolerance.

Better answers can be obtained only by going on to production. The cost of shale-derived fuel is essentially dependent on the cost of the shale crude. If shale oil crude costs are competitive with petroleum crude, synjet from shale oil should be economically competitive with conventional jet fuels.

Refining of jet fuel from shale oil has been developed to a high degree, so that conclusions can be regarded with good confidence. These Air Force meetings were well attended from manufacturing and airline operations, oil companies, laboratories, study groups and others, so important details are now in the appropriate organizations.

One more observation may be pertinent. Pre-processed shale oil will probably disappear into the pipeline network and refinery feedstocks with an absence of fanfare; it will simply add a very small amount to the quantity of natural crude being processed, now around 15 million bpd. Unless some specific reason is advanced, shale crude will probably end up in jet fuel no more nor less than in other refinery products.

The Air Force will buy as much shale crude as it can, initially working toward 40,000 bpd from which it could operate its domestic-based aircraft. Maximum total peacetime requirements of the DoD, Army, Navy, USAF and Marines, is about 400,000 bpd, so that should be the upper limit of potential DoD buying. DoD's goal is independence from foreign crude interruptions.

With those commitments considered, shale oil offers the possibility of a reliable domestic source for high-quality aviation fuel. It should come on the market at prices directly competitive with conventional jet fuel. Even if dedicated refineries are built to maximize shale crude production into jet fuel, at something like 25% higher costs than for conventional refineries, the finished fuel costs still appear competitive.

Members of the aviation community concerned with jet fuel supply reliability should consider whether reliability of a wholly-domestic source with assured quality is worth an insurance premium. If an aviation-supply arrangement were negotiated at existing prices and the world price of crude oil declines, then aviation would be paying higher than market price for the insurance. If, however, there is a disruption in foreign supply and fuel prices again escalate upward, U.S. aviation participants could be protected from both price and availability disruption.

The availability problem would seem to be greater than that of soaring prices; with higher prices, each airline at least has the option of continuing operations. Without fuel, no option remains.

If this insurance were bought, it could also be effective against increasing demands of diesel and other middle-distillate customers. This question of market competition also seems worthy for serious consideration by the aviation community as a whole, or by individual operators.

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Chapter 9

Cryogenic Fuels and Other Aviation Propulsion

Board Room Briefing No. 9

1. This author believes that advent of LH_2-powered aircraft or of a "hydrogen economy" is not imminent. But, recognizing the inevitable decline of fossil fuels, hydrogen should some day become man's predominant portable fuel. Various economic or sociological circumstances could speed the time, but the author doubts technological development will accelerate the process. However, in an arena as varied, as vast and with such competitive stresses as fuel and energy, it may be shortsighted to downgrade these possibilities.

2. Having proposed a case for LH_2 in the indefinite future, this author must state a case for liquid methane (LCH_4, which is the same as liquid natural gas, LNG). LCH_4 does not equal, but it approaches LH_2 in many respects. It is cleaner, lighter and more efficient than other hydrocarbons. An airplane powered with LCH_4 would resemble, have many of the advantages, and suffer many of the disadvantages of an LH_2 airplane. Although also cryogenic (liquid only at low temperatures, regardless of pressure), LCH_4 requires less insulation, handling, and considerably less energy to liquefy. More significant, and this is a personal belief, methane may become more economical and available worldwide than other fuels, including petroleum. If that opinion proves valid, confirming evidence should emerge before 1990, perhaps before 1985.

3. Hydrogen is currently expensive to produce and liquefy. It is doubtful that laboratory developments will significantly reduce these costs. But at least one example has shown that hydrogen could be competitive now with Jet A, using thermodynamic economy and selling byproducts advantageously. It is speculative whether similar production arrangements could be widespread.

4. Nations like Japan and those in western Europe, which are short on energy feedstocks for synthetic fuels, may view hydrogen with much more interest than the U.S. Particularly depending on how they account for their energy costs, such as nuclear power, they could price hydrogen advantageously. There is international interest in hydrogen as a universally available and uniform, excellent fuel. Some nations are concerned about the Greenhouse Effect and the value of hydrogen in reducing mankind's production of carbon dioxide.

5. There is the significant question of whether man's production of carbon dioxide will affect the earth's climate and what its effects may be on agriculture, height of sea level and other vital concerns. Current studies here and in Britain are unlikely to reach conclusions for another year. When study results are available, it is debatable how many years of observation will be required to see if they correlate.

6. As discussed in Chapter 7 under Deep-Earth Methane, natural earthquake and volcanic activity may affect the earth's atmosphere more than man could ever contribute. Since far more CO_2 is dissolved in oceans than exists in the atmosphere, small differences in ocean/atmosphere interchanges may affect the atmosphere's CO_2 more than burning all our fossil fuels, for example. It is doubtful mankind will have satisfying answers to these questions for tens of years, if ever.

7. Geologic evidence indicates that, during the past million years, the earth has enjoyed less than 50,000 years of weather as warm as in man's recent past; the past 10,000 years may have been unusually warm. If the earth's long-term climate leans toward its colder past, and there is evidence this may already be the trend, increased heating due to carbon dioxide may be not only unobjectionable, it could be desirable.

8. These climate questions could affect the continued burning of fossil fuels, which releases CO_2, particularly if the world's forests continue to be cleared and if less CO_2 is consumed by plant life. Synthetic fuel production generally releases much more CO_2 than does preparation of other fuels, followed by combustion of the fuel itself. So, if CO_2 should be confirmed as a world concern, synthetic fuels will receive sharper review than other fossil-based forms of energy.

9. If atmospheric CO_2 becomes a serious concern, political pressure could develop against synthetic fuel production and hydrocarbon fuels. Methane would remain the most favorable fossil fuel. With hydrogen derived by water-splitting (not from fossil fuels), production and combustion of hydrogen would not affect the CO_2 balance. Hydrogen could then become a favored fuel on a world-wide basis; it also could be produced by countries without fossil feedstocks. Because it also would be uniform around the globe, hydrogen could be touted as a universal aviation fuel by nations poor in fossil resources.

10. General Aviation problems with gasoline price and availability will probably increase. The best long-term solution is probably to build new engines capable of operating on jet fuel. Some GA recreational operations may be able to use automotive gasoline, but not likely for commercial (pay) operations.

11. No gaseous fuels appear suitable for aviation. Alcohols are not favorable. Both ethanol and methanol have low energy content, while ethanol is inherently expensive in dollars and energy. They may be used as gasoline-octane additives, but neither appears suited for widespread aviation use. Some applications could be feasible under unusual circumstances.

12. The density of liquid methane is low but its energy content is high. Since it requires cryogenic tankage, it must be stored in the fuselage of aircraft. Small aircraft with enough

available volume (weight is no problem) may be able to use liquid methane profitably. It is equally attractive for larger aircraft which can accept the volume limitation. It is an excellent fuel and less than half the price of avgas, in some cases, less than a third.

13. Nuclear power and other exotic propulsion concepts do not appear to have any early promise for either commercial or general-aviation operations.

Hydrogen Rationale

Generally speaking, there are six arguments offered for liquid hydrogen as a primary aviation fuel.

A. As petroleum production depletes and prices rise, the price of hydrogen may decrease. If capital and production costs for synthetic fuels are high and hydrogen will become the ultimate portable fuel, then it may be economic to switch to hydrogen directly from petroleum.

B. After petroleum the U.S. has generous fossil reserves and can manufacture synthetic fuels fairly readily. Other nations, like Japan and many in Europe, do not have adequate hydrocarbon feedstocks. There is already interest in hydrogen as a universal aviation fuel; other nations may promote it increasingly.

C. If nuclear power, solar power or any other major energy source becomes economical, production of hydrogen from that source is likely to be more economical than transmitting and storing electricity. A "hydrogen economy" could augment aviation use of hydrogen.

D. There are many ways of producing hydrogen; more economical methods may be developed from the active research programs in many nations. Liquefaction costs may reduce. Sale of byproducts, taxes and other regulations could favor hydrogen and make its price competitive.

E. If the Greenhouse Effect becomes an issue because of increasing carbon dioxide in the atmosphere, society, or other nations may clamor for reduction of synthetic fuel production and burning of hydrocarbons. If produced from water, neither hydrogen production nor combustion creates or releases CO_2.

F. Hydrogen has strong attributes as an aircraft fuel. It is light, high in energy content, burns with a very low flame radiance, releases minimum pollution (only NO_x), and creates no carbon dioxide. It may be useful for laminar flow control and drag reduction. It is probably the only fuel with which a "conventional" airplane can achieve semi-global range. At high supersonic or at hypersonic speeds, hydrogen is probably the best candidate fuel.

The disadvantages with hydrogen are: first, its current high price; second, its low density; third, it must be used in the liquid phase and its liquefaction temperature is very low, -423°F. As a liquid, hydrogen requires expensive insulation, while the capital and energy costs of liquefaction are high; there has been some question of safety with hydrogen.

This chapter will deal with these issues briefly. The pros and cons involve so many details that much discussion and background, particularly about production and the "hydrogen economy," is deferred to Volume 2. In condensing the discussion, it is necessary for the author to draw conclusions and express opinions, without elaborating points that many may consider important. Nor does Volume 2 settle the issues; conclusions regarding hydrogen depend strongly on the concepts of energy and fuel that each assessor perceives.

The same problem accompanies each component of the different issues: depletion of petroleum; economics of synthetics; economics of nuclear, solar and other power sources; national plans and preferences; future technological and industrial developments, hydrogen application problems and costs. Combining speculation from these issues simply compounds the differences of opinion.

So the issues above are discussed in turn and the author's opinions are offered on each. The conclusions and consequences are listed in the Board Room Briefing. Other opinions may be more valid, while future developments could support or defeat any of them.

Petroleum Depletion — As has been stated in Chapter 4 and elsewhere, it is the opinion of this observer that U.S. oil production has not peaked, that it will be sustained in response to market demand, and that it may increase in percent of U.S. oil consumption over the next 10-30 years. Those who see U.S. oil production already in terminal decline necessarily regard the entire subject of hydrogen ascendancy in a different light. The possibility of significant political or economic developments in natural gas or EOR could have a strong effect in deferring petroleum depletion. World methanol could have a significant effect, as could other developments in primary hydrocarbon fuels (coal, lignite, peat).

Hydrogen Price — The cost of producing hydrogen has historically been higher than for other fuels because of the energy required. Costs depend heavily on the assumptions made. In 1979 the National Research Council[9-1] concluded that, with 1980 dollars and electricity at $0.03/KWh, mine-mouth coal at $0.96/10⁶Btu and natural gas at $3.15/10⁶Btu (same per Tcf), a reasonable comparison would be:

Costs of Fuels per Million Btu

Gasoline from Shale	$ 5.05	
Gasoline from Coal	7.80-10.55	(Liquefied
Methane from Coal	6.00	@ $4.40)
Hydrogen from Methane	6.80	11.20
Hydrogen from Coal	9.50	13.90
Hydrogen by Electrolysis	19.65	24.05

This information was taken directly from Reference (9-1), which obtained it from Reference (8-1). It therefore can be compared with the other data of Figure 8-2. A variety of studies, including those of NASA,[9-2] IGT,[9-3] and Los Alamos,[9-4] generally agree with these relationships, if not precisely with these figures. Others have arrived at different conclusions with valid assumptions but, in general, comparisons are similar to that given here.

But byproducts, taxes, pricing and other factors can shift the picture. Hydrogen proponents point out that prices are not fixed and immutable. In October 1980, the General Scientific Corporation, a subsidiary of Pacific Lighting Corporation, which holds a series of energy related companies, including The Southern California Gas Company, made a formal proposal[9-5] to the DOE to deliver liquid hydrogen to Los Angeles International Airport at a price per Btu lower than the price of conventional Jet A. The proposal was not accepted; in its solicitation, the DOE was seeking more immediate applications for alternate energy sources, largely domestic alcohol production.

But the proposal made a very important point. It showed what could be accomplished under favorable industrial and economic conditions. The essence of the proposal was outlined in a letter from Edward H. Erath, President of General Scientific Company, to the DOE:[9-6] ". . . This proposal is to develop the General Scientific Liquid Hydrogen Aircraft Fuel Project. It is intended to produce liquid hydrogen from coal, using the continuous steam iron process and producing both electricity and heavy water as by-products. The by-product electricity and

environmentally desirable features of the continuous steam iron process enable the production of liquid hydrogen aircraft fuel at a delivered price less than that presently paid for aviation kerosene. When fully used by the airlines, liquid hydrogen will directly replace over one million barrels a day of middle distillate fuel."

"This project will con..ie commercial size equipment to supplement the aviation fuel supply at Los Angeles International Airport with 200 Tons per day of liquid hydrogen, the equivalent of 3440 barrels of oil per day and replace over 200 megawatts of base load oil fired electricity generation."

The proposal itself goes on to explain, "The low hydrogen fuel cost is possible because of cogeneration of byproduct electricity as the gaseous hydrogen is produced from coal by the IGT continuous steam iron process. Approximately 200 megawatts of cogenerated electricity will be produced and sold by the facility." California's Public Utilities Commission sanctioned this sale of electricity at 7.145 cents/KWh to the Southern California Edison Company, backed by the Public Utility Regulatory Policies Act of 1978 (PURPA).

As a part of the project, Lockheed proposed to study the liquid hydrogen market, to design hydrogen conversions for L-1011 aircraft and, in cooperation with Continental Air Lines, would have planned to operate a small demonstration fleet to use the 200 tons/day of LH_2.

While unsuccessful, this proposal illustrated the possibility that special combinations of energy production and marketing, financing and taxes, may produce surprising results. It suggests also that other types of synthetic fuel production might develop favorable arrangements with which to compete.

It is interesting that often hydrogen costs are based on electric power costs for electrolysis, so that higher costs for electricity produce higher costs for hydrogen. But here is an example where a relatively high cost of electricity, sold as a byproduct, was instrumental in lowering the cost of hydrogen production.

As has been mentioned, water can be split into hydrogen and oxygen at low temperatures with relatively high electrical power applied (see table above). The total thermal efficiency from water to gaseous hydrogen in the pipeline is about 24-35%. It can also be split at high temperatures by heat alone, at about 1200°C. Between these two extreme conditions is a whole spectrum of electrochemical and other processes, many of which are being investigated.

Some reduction in cost from straight electrolysis should be expected. But it is not believed that any laboratory will produce low-cost hydrogen. Thermodynamics and chemical bonds are about the same in the various projects. The author believes only special political, economic or industrial combinations can make hydrogen competitive in price.

Nuclear, Solar and Other Power — Nuclear electric power has been cheaper than that produced from other sources. When hydrogen is to be produced or liquefied on a large scale, at least in the past, the cheapest way to do it was with nuclear-generated electricity. But restudies of nuclear plant designs and enhanced protective systems have increased nuclear light-water reactor power costs. It is currently speculative to assume whether fast-breeder reactors will emerge and where nuclear fission costs will settle down.

Considering that electrolytic production of hydrogen is such an expensive method, there appears to be no means by which nuclear-generated electricity costs can be reduced to yield a competitive product. Nuclear fusion is at least twenty years from commercialization and may offer little economic improvement, if any.

Fusion plant costs are completely unknown and appear likely to be higher than for fission plants. In fission plants, particularly with fast-breeder reactors, fuel costs are already low to negligible. When waste-disposal costs are settled on an equitable basis, nuclear fission costs should stabilize. While no fuel wastes are produced with fusion, the reactor's protective blanket shield will be heavily bombarded with neutrons, will develop much radioactivity, and will present a comparable disposal problem, which some say may be worse.

Here again, however, accounting or political policies could upset the balance. Nations which subsidize their nuclear industries could show a lower price of hydrogen on their books. Nuclear powerplants can use off-peak power to manufacture hydrogen. Other powerplants using "renewable" energy can do the same, without the incremental fuel costs of fossil-fuel-powered plants. Depending on how plant capital amortization and other charges are spread, a nation's accounting method could show favorable hydrogen costs.

Some Canadian powerplants are already actively studying hydrogen production as a means of storing off-peak power, particularly in the eastern provinces with excess hydroelectric power, but also in Saskatchewan.[97] Some are expected to act favorably on the studies. The hydrogen will be burned in aviation-type gas turbines directly during peak load periods, instead of using jet fuel. This type of operation doubtless accounts for hydrogen at a relatively low cost, ***a lower cost than the powerplant would pay for jet fuel!***

Synthetic Fuels — Particularly if shale oil is economically competitive, the author sees U.S. synthetic fuels stretching out much longer in history than our oil epoch, indefinitely for all practical purposes. But a proponent of hydrogen sees synthetic fuel costs as speculative as the cost of hydrogen. Admittedly, synthetic fuel development costs appear to be rising faster than costs of other fuels or the rate of inflation. But now that the boom in oil and synthetics has sagged, the cost of development in both fields may recede back to parity with the rest of the economy.

However, mining costs, synthetic plant costs, operating costs and infrastructure costs are not known. The total capital investment for any synthetic fuel production is certain to be high. The hydrogen proponent observes that his production investment and costs should not be assumed higher. Costs for synthetics may give him ample leeway to come in at a better price. The hydrogen proponent sees the high costs of mining and handling synthetic feedstocks as a perpetual, tempting and attainable target.

Nations which do not have adequate fossil fuel feedstock resources would presumably buy their synthetic crudes and fuels on the market in the same way they now buy petroleum crudes and fuels. Whenever they can produce and use hydrogen at a lower net cost, presumably they will do so. The hydrogen proponent concludes that day will come and he believes it to be relatively soon, possibly within the current petroleum trend.

Realistically, when the next crude oil disruption takes place, if the price of crude jumps again as many feel certain, who is to say whether the cost of manufacturing hydrogen will escalate as fast as we have seen the cost of synthetic developments rise? The gap could close or reverse. Having abandoned their bets on shale oil, how would Exxon regard the relative prospects in hydrogen?

Hydrogen Production — It may be expected that the energy cost of hydrogen production development will decrease through technological improvements. In general, electrochemical processes appear better in energy than straight electrolysis. They may become more economical, overall, in dollars. But it is the

opinion here that, although the improvements will be worthwhile and cost reductions should be expected, they will not be substantial enough to reverse the cost relationships between hydrogen and other fuels.

Nevertheless, the General Scientific Corporation proposal was legitimate, fully coordinated and approved, under firm contract, it would have delivered liquid hydrogen at a lower price than Jet A. Although the combination of circumstances was special, it is possible that other special combinations can be assembled by entrepreneurs. The author doubts this can be done on a nationwide or worldwide scale, but that possibility exists.

It should be observed that similarly favorable thermodynamic and economic combinations may be developed for synthetic fuel production and other fuel developments.

In fact, the author contends that, with anything like a favorable set of circumstances in this country, natural gas would re-order the nation's and perhaps the world's energy picture. The opinion here is that it would make this entire report academic.

Each energy proponent is rightfully enthusiastic about what his choice could accomplish under favorable circumstances! The author contends that favorable circumstances have been created for selected resources (solar, alcohol) which cannot produce energy at the needed rate, while those which could (natural gas and EOR) are hobbled. This condition may not be entirely accidental; unshackling natural gas or EOR would upset the existing situation.

Back off the soap box and on the record, it appears that politics, regulations, taxes and other considerations control the marginal price of synthetics and cryogenics almost as effectively as they do the price of petroleum, enhanced oil recovery and natural gas.

Greenhouse Effect — Concern is that CO_2 in the earth's atmosphere acts like glass in a greenhouse. Solar radiation passes through the atmosphere and its CO_2. When this radiation is absorbed by the earth's surface or other materials, converted to heat and partially re-radiated as infra-red, the infra-red radiation is trapped by CO_2 in the atmosphere. The amount of CO_2 in the atmosphere is very small, so it can be increased significantly or doubled by relatively small additions.

Another component which is not well understood is the exchange of CO_2 between the oceans and the atmosphere; oceans contain far more CO_2 than does the atmosphere. Additional CO_2 in the atmosphere may stimulate plant growth, which uses CO_2 and releases oxygen. With less-developed nations scrounging for firewood, jungles like the Amazon being cleared, and similar developments, it is very difficult to forecast the outcome for world CO_2 balance.

Some observers have concluded that these interactions are so complex and climate trends so gradual and erratic from year to year that, by the time we could verify any hypothesis, the trend would probably be too well established for man to reverse it.

At the same time, others have noted that the earth appears to be in an unusually warm phase of a 10,000-year warm cycle and that the "normal" climate is much colder.[2,24] David Lindahl at the Library of Congress has observed that temperatures recorded at both poles indicate that the earth may be slipping back toward a mini or a real ice age.

Another consideration may be the dust released during large volcanic events and the fact that weather alteration has been attributed to these events in the past. The fact that volcanic events and earthquakes evidently release large volumes of CO_2 and other gases[24] may affect the atmosphere more than man can contribute. Whether the comment is responsible or not, some have at least conjectured that, if man burned all the hydrocarbon fuels reasonably available to him and also disturbed much of the plant life on earth, most of the excess CO_2 which would result would be absorbed into solution by the oceans and the earth's climate would not be greatly affected.

It really appears that we don't know. Some calculations have indicated that only two or three degrees centigrade average change can alter the climate, with greater effects in the temperate zones than nearer the equator. Some areas would expect less rainfall, some more. It isn't clear who might benefit or suffer and to what extent. But a fair consensus is that the effects likely would disturb present agricultural patterns considerably, so that any change would be significant to world agriculture.

The U.S. Weather Service has a mandate from Congress to complete a comprehensive report over a period of two years, which will end about the close of 1982. A similar study is underway in Britain, where there had already been much interest and activity. But, as has been said, decades of data may be needed to verify these study results and, by that time, the trend might be irreversible.

Probably any opinion on the subject at this point is completely unfounded. But if experience with the SST weather modification predictions due to ozone gives any indication, those dire forecasts were not only refuted later, effects were found to be opposite from the predictions.

Hydrogen Liquefaction — First, let there be no doubt: compressed hydrogen gas (or any gaseous fuel) is not suitable in aircraft. As an illustration, compressed methane (CNG or compressed natural gas) is used considerably abroad in some automobiles and trucks, largely in fleets. Even at pressures near 3000 psi, limited energy can be stored in a tank which can fit into an automobile. And the tank is extremely heavy, comparable to industrial gas bottles commonly seen for oxygen. With such an installation, a typical automobile range is well under a hundred miles. Compressed-gas ground vehicles are like battery-powered vehicles, heavy and inherently range-limited. It should be evident that the heavy weight and restricted fuel supply make compressed gases utterly impractical in aircraft.

Liquid hydrogen is cryogenic. At room temperature, its liquefaction pressure is 2000 atmospheres (30,000 psi). It must be cooled to −423°F, where it can be held liquid at atmospheric pressure. As would be expected, cryogenic temperatures present significant engineering challenges, although the NASA Space Program has developed much technology, equipment and handling procedures. While cryogenic insulation is sophisticated, boiloff rate is low, typically 0.5% per day, or as low as 0.02% per day in bulk storage.

But hydrogen liquefaction is expensive. It takes about the energy in a pound of hydrogen to liquefy a pound, about a 50% thermal efficiency. In large quantities, this liquefaction takes a very substantial plant and equipment system. As shown in Figure 9.1, a plant to maintain liquid hydrogen sufficient for aircraft at O'Hare Airport would cost over a billion in 1979 dollars.[9.2] Instead of venting to the atmosphere, it is more economical to collect boiloff from aircraft which are out of service and during fueling operations. So the airport would have a full re-circulating LH_2 system, with return of gaseous hydrogen from all its fueling stations. The original gaseous hydrogen would be delivered to the airport by normal underground pipeline, unless the hydrogen manufacturing plant were also located at the site.

It has been suggested that magnetic liquefaction may be developed to a scale for commercial LH_2, reducing liquefaction costs. The DOE Los Alamos Laboratories are working on this

project. Magnetic liquefaction is in its early stages for commercial application and one might expect anything from 5-20 years for process and hardware development.

Hydrogen Future — Hydrogen supporters point out that the U.S. has a variety of alternatives for petroleum and after petroleum. Other countries, particularly Japan and our European trading partners, are not so well endowed. The U.S. may assume that its aviation fuel needs can be met for some time with petroleum and then for an indefinitely long period with shale oil, coal liquids and a variety of other resources. Our trading partners may conclude they would simply be replacing foreign exchange problems with OPEC for foreign exchange problems with other countries.

These resource-poor nations may insist on hydrogen as a universal and uniform aviation fuel, producible from water by nuclear, hydroelectric, solar, geothermal, or any other power available. Depending on how they determine their costs, taxes and so forth, other nations might conclude that hydrogen from domestic power sources is preferable to synfuel from sources they do not have. At any rate, that is one reason given for future emergence of liquid hydrogen.

Liquid Methane (LCH_4, LNG, or liquid natural gas) — Liquid methane is best discussed along with LH_2. In many respects, LNG approaches both the advantages and the disadvantages of LH_2, not fully attaining the extremes. It is cheaper to manufacture or can be obtained directly from wells, easier to liquefy and handle, but contains less energy per pound. An airplane powered with LCH_4 does not equal the performance achieved with LH_2. As seen in Figure 9-2, it is only marginally superior to an aircraft with conventional or synthetic jet fuel.

While LNG can be liquefied directly from natural gas, it cannot be deri e 'rom water and energy alone as can hydrogen; it requires a nydrocarbon feedstock.

Some characteristics of both the fuels and aircraft designed to operate with LH_2 and LCH_4 are compared in Figure 9-2, which is essentially taken from Reference (9-8). The information in Figure 9-2 has been criticized from at least two views. First, some have commented that it is now out of date and that more recent comparisons would show better relationships among the three candidates, SynJet A, LCH_4 and LH_2. That is no doubt true.

Second, all three fuels were derived from coal, in order to present a common basis. But synjet can be produced more cheaply from shale; LCH_4 can be natural gas liquefied directly, and there are cheaper methods for producing hydrogen. All these objections are valid. But departure from these assumptions may lead to even less representative comparisons among the three fuels.

If an immediate selection of future fuel were needed, a newer study would be desirable. In any new study, the groundrules should be given greater care than the analysis itself. But it is unlikely that any decision need be imminent or that a new study will be made with negotiated and accepted groundrules. So these results are probably as good as we need now and the best we can expect for some time.

The marketplace still must determine whether or when synjet can compete with conventional jet fuel. A movement on to cryogenic fuels will be stimulated by price competition, by a need to reduce release of CO_2 into the atmosphere, or by foreign countries urging a universal airline fuel.

Liquid Hydrogen as an Aircraft Fuel — Existing aircraft engines can be modified readily to operate on liquid hydrogen. Ordinarily, the basic engine would not be changed at all; modifications would be limited largely to fuel controls. Operation would be excellent and all performance criteria would equal or exceed performance with standard fuels. These conclusions are based on flight tests several years ago with a hydrogen-powered aircraft.

Figure 9-1

Capital Facility Costs ($Millions)
(Chicago-O'Hare 40,000 BPD Equiv.)

CAP. ITEM	SYNJET A (SHALE)	SYNJET A (COAL)	LCH_4 (COAL)	LH_2 (COAL)	LH_2 NUC. ELEC.
PROD. PLANT	1,503	2,211	1,590	1,348	7,595
2500 MI. PIPELINE	63	63	322	379	
MFG. SUB	1,669	2,377	1,912	1,727	7,595
AIRPORT LIQEFACTION	—	—	583	1,050*	1,050*
STORAGE	NEG.	NEG.	14	72	72
AIRPORT SUBTOTAL	NEG.	NEG.	597	1,122	1,122
TOTAL SYSTEM	1,669	2,377	2,509	2,849	8,717

*LARGER THAN ANY NUCLEAR POWERPLANT BUILT.

Figure 9-2

Cryogenic Aircraft Fuels (Liquid Methane LCH_4, Liquid Hydrogen LH_2) Compared with SynJet

Subsonic Aircraft Costs (400 Passengers, 5500 N. Mi. 0.85 M)

	SYNJET A	LCH_4	LH_2
BOILING POINT (ATMOS)	350°F	− 258°F	− 423°F
GROSS WEIGHT-LB	512,000	497,000	372,000
PRICE - $MILLIONS	44.5	48.1	43.1
DOC - CENTS/SM	2.15	2.17	2.18

There is no gumming or fouling, while hydrogen burns with an almost invisible flame. Due to low radiant heat from the flame, the temperature of fuel nozzles, engine combustors and turbine components — virtually all the expensive hot-section parts — will be lowered. Engine maintenance and inspection costs could reduce significantly. Reduced radiant heat could offer the possibility that higher stresses could be accepted and engine performance increased.

Modifying an existing airframe for a hydrogen fuel system is another matter. As has been suggested, expensive, sophisticated insulation is required. As a result, it is impractical to insulate flat vessels like the average wing tanks. Except in a few areas, the wing thickness would be insufficient to contain the insulation and appreciable fuel volume. So all or nearly all of the fuel must be carried in the fuselage.

Tanks would be expected to be cylindrical, not because of internal pressure, but to minimize the insulation costs and weight. Since most heat enters such a tank by radiation, rather than by conduction, the geometric shape of tanks is important. Surface area must be minimized. It is likely that tanks will be required both fore and aft of the passenger cabin to maintain balance, and so it is unlikely that access would be maintained between the cabin and the cockpit.

As part of the General Scientific proposal to DOE, Lockheed would have modified aircraft to be operated by three airlines out of Los Angeles, a trunk, a local and a freight airline. It would have been interesting to see how those airplane modifications would have worked out, as well as the hydrogen handling and flight operation details.

New engines and airplanes optimized for liquid hydrogen would have superior performance, would be smaller and lighter than conventional aircraft, and would burn fewer Btus per passenger-mile. A brief comparison of aircraft using synjet (or Jet A), liquid methane and liquid hydrogen is shown in Figure 9-2.[9-8] Belaboring the obvious, results of this table depend on assumptions; they have also been subjected to criticism from other sources, but they are believed generally representative.

Even the SynJet A airplane could not be in service in less than eight years, the time it takes to build and certificate a new engine of conventional design. The LCH_4 and the LH_2 aircraft may not take longer, but a new cryogenic fuel production and distribution system is likely to require more time.

Considering such relatively small differences as the direct operating cost comparisons, we should conclude only that operating costs are directly comparable for all the fuels. The synjet airplane and the liquid methane airplane are similar in size and weight and carry nearly comparable loads of fuel. The LH_2-powered aircraft is 20-25% lighter and carries only about one-third the weight of fuel. It should be noted that the comparison is made for a 5500 n. mi. mission. Long ranges are more favorable to cryogenic aircraft.

There is at least the potential of using either of the cryogenic fuels to cool the aircraft skin, perhaps extending regions of laminar flow and achieving drag reductions up to 25% in cruise flight. At the present time this concept exists only on paper and one of the recommendations of the Ad Hoc Executive Group (AHEG) of the International Symposium — Hydrogen [illegible] Air Transportation [illegible] is that it be explored experimentally. [illegible] successful, the concept should be more practical than [illegible] air to maintain boundary layer stability. There [illegible] belief in the industry that some further laminar [illegible] obtained by airfoil design without pumping at skin [illegible]

As a corollary to that interest, there have been several [illegible] sions of USSR interest in hydrogen. As one third [illegible] the IIASA study [illegible] Soviet participants observed that [illegible] long-term plan is transition to a hydrogen-based [illegible] distinguished from an electrical based economy. The [illegible] tion press has noted Soviet interest in aviation hydrogen [illegible] more than one occasion. After the Paris Air Show [illegible] ***Aviation Week and Space Technology*** reported [illegible] said development of future aircraft includes a plan [illegible] hydrogen as the main civil aircraft fuel by the late [illegible] early 1990s. Some feel that these are probably statements from USSR enthusiasts, like U.S. statements on colonizing the planets. On the other, Soviet economics may figure [illegible] ferently.

One final discussion may be pertinent regarding cryogenic fuels and the prospects for supersonic transports. Range or cruise efficiency is proportional to the cruise speed or Mach number (M), the lift/drag ratio (aerodynamic efficiency), the reciprocal of the specific fuel consumption (propulsive efficiency), and the log of the ratio of fuel-empty weight to fuel full weight (essentially the size of the fuel tank, or indirectly the structural efficiency).

$$\text{Cruise Efficiency} = M \times L/D \times 1/SFC \times \log_e W_f/W$$

All other factors remaining the same, the airplane with highest cruise speed will have the longest range.

All other factors do not remain equal as speed varies, however, and near the speed of sound, L/D decreases markedly. It is desirable to cruise at speeds either below this "drag rise" or well above it. At around Mach 2, the Concorde still suffers from an unfavorably low combination of M and L/D. The defunct U.S. SST was designed to cruise at the highest speed permitted by its fuel, Jet A.

(Aircraft internal heat was rejected to the fuel before it entered the engine burners. Because of high outside stagnation air temperatures, it was uneconomic to reject heat outside the airplane.) With standard kerosene fuel (then at 11 cents/gallon) the optimum cruise speed was established at Mach 2.7. At speeds above Mach 2.7, more heat was absorbed and produced inside the airplane than the fuel could accept before it coked at the engine spray nozzles (with a suitable safety margin applied). If cruise speed could have increased further without heat rejection problems, the next barrier was loss in propulsion efficiency above about Mach 3.5, approaching the combustion limits of kerosene. The titanium structure would have been capable of going beyond Mach 2.7, perhaps to 3.5.

Particularly with kerosene now over a dollar a gallon, there appears to be no possibility of a kerosene powered SST, if

anyone wanted one. On the other hand, an SST powered with liquid methane or hydrogen opens up a new vista, not only in combustion, but in the large cooling sink afforded by the cryogenic fuel itself. There is reason to expect that a cryogenically-fueled SST would be more economical and use less fuel per passenger-mile than subsonic aircraft. It could be economical only if the rest of aviation also used liquid hydrogen and shared in the fuel liquefaction and distribution costs.

And, still further out, there is the AeroSpaceplane concept which was explored prior to the Space Shuttle selection. An airplane fueled with liquid hydrogen could take off from a runway, using atmospheric oxygen instead of liquid oxygen that the Space Shuttle carries in its vertical launch. On climbing through the atmosphere, the AeroSpaceplane design would use the heat-sink capacity of its liquid-hydrogen fuel to liquefy air, separate out nitrogen from the oxygen, discard the nitrogen, and proceed on into orbit with both liquid hydrogen and liquid oxygen.

Safety with Liquid Hydrogen and Methane

Discussions of liquid hydrogen often surface concern about safety, the so-called "Hindenburg Syndrome." Some experience has been gained with the space program and other operations. NASA has conducted limited experiments and, under contract to NASA, both Lockheed[9-11] and Arthur D. Little, Inc.[9-12] have made assessments. From viewing movies of hydrogen cloud movements and the other information considered, this author would agree that the crash-fire hazard of kerosene, LH_2 and LCH_4 are generally comparable. From the viewpoint of a passenger, LH_2 appears to be preferable.

For passengers who survive a crash, any of the fuels is likely to ignite, kerosene because it breaks into a fine mist in impacts at speeds near landing or takeoff. The A.D. Little report remarks, "Our basic conclusion is that the crash fire hazards are not significantly different when compared in general for the three fuels, although some fuels showed minor advantages in one respect or another."

In summary, hydrogen burns rapidly, creates a smaller fireball and emits less radiant heat. Hydrogen also creates less hazard in a pool fire. Vapors of the two cryogenic fuels can disperse downwind and present a hazard and, perhaps surprisingly, remain near grade level. (It is said that approximately 3/4 of the potential energy difference, represented by the hydrogen's density and temperature, is dispersed in violently turbulent mixing with the atmosphere and only 1/4 in vertical motion).

Hydrogen has wide flammability limits and is most likely to ignite, but this increases the chance of earlier ignition and may reduce downwind fire hazard. In a hydrogen fire, cabin occupants should wait inside between one and two minutes for the fire to burn out, with little radiation, rather than to attempt an early escape.

General Aviation Propulsion and Fuels

Some material presented earlier in this report is applicable to general aviation aircraft operations and because of that, the sequence adopted here is different than in a paper directed solely toward general aviation. It would be more natural to start where we are in the aviation gasoline situation and, from that base, proceed on into the prospects for alternatives. Instead, with the close proximity of methane discussed above, it will be reviewed first, then gasoline, and lastly the more advanced prospects for general aviation (GA) propulsion.

Those readers active or interested in general aviation need no reminding that its problems are primarily in availability and price of aviation gasoline. Since aviation gasoline demand is only around 5% of aviation fuel, its difficulties are further accentuated by a thin market. As more general aviation grows into turbine-powered equipment and uses jet fuel (commuter airlines for example), gasoline may become increasingly scarce.

Alternative GA Fuels

A major move of automotive fuel toward diesel, methanol or methane could either improve the aviation gasoline situation or worsen it. If some refiners decided to retain a small gasoline output or if some refiners specialize toward producing gasoline, the effect on aviation could be salutary. However, with the major automotive gasoline market receding, other refiners might modify their plants to eliminate gasoline production entirely. They might use their hydrotreating capability toward meeting the stronger middle-distillate demand. Further compounding the problem is the present need for three grades of aviation gasoline: 80 octane, 100 octane and 100 low-lead. Alternatives to the present situation are highly desirable.

There has been recent interest in methanol and even ethanol as possible aviation fuels. The case for ethanol appears particularly poor because, in addition to its low energy density, there is small likelihood that it can be made available at competitive prices. Except for possible isolated cases, this author concludes that the only application ethanol may have in aviation is as an octane enhancer. Other alternatives, including methanol for octane-improvement, would seem to eliminate ethanol from future consideration. For the farmer who would like to produce his own ethanol, the reply would be to make methanol instead.

Unlike ethanol, methanol offers good prospects for stationary turbines. The primary problem of methanol in aircraft, its low energy density, reduces range/payload severely. So, if some unique operations, perhaps local flying or other short-range specialties, can accept its range/payload penalties, then methanol may provide attraction for a few turbine-powered aircraft.

Methanol appears more favorable in piston-powered aircraft. Because of its good octane characteristics, engines powered with methanol can be run to their mechanical limits; they are not limited by the fuel. At higher altitudes, methanol burns at cooler temperatures than gasoline, so rich fuel mixtures are not required for engine cooling. One private group which has been experimenting with methanol contends that they get better mileage at high cruise altitude than with gasoline. Unfortunately, their aircraft instrumentation has not been capable of providing a conclusive assessment. Propulsion experts from industry, government and laboratories have been unanimous in discounting that possibility. The known altitude disadvantages of gasoline are not expected to be overcome by methanol due to its tremendous disadvantage of about 50% less energy per gallon.

Government offices have contended that the answer to this debate is not likely to favor methanol, nor is the answer of wide public interest. For those reasons, if methanol offers some advantage to GA, either industry or users will have to evaluate the possibility for themselves. No governmental department intends to resolve the issue.

It may be pertinent to mention here that neither the Government nor the FAA specifies the fuels used in aircraft or aircraft engines. Technically, any individual may operate his equipment with any fuel he likes, so long as the equipment is licensed to do so. Anyone can apply for and receive a license for any combination of powerplant/aircraft with any fuel. The problem is in the cost of demonstrating that the combination is safe.

Because of this expense, the manufacturer of a new engine usually applies for certification with fuels he thinks important to

his engine sales and customers. For example, it is believed that all U.S. commercial jet engines have been certificated to operate on both Jet A, Jet B and mixtures of the two. During certification of each engine type, the manufacturer must demonstrate that his engine's power ratings, safety levels, maintenance procedures, etc. are satisfactory with all the fuels for which the engine is to be licensed. It is this demonstration which may be expensive.

Similarly, when an airframe manufacturer specifies an engine for his airframe, he must demonstrate that the aircraft and its fuel system are compatible with that engine and with each fuel for which the type certificate is sought.

An engine manufacturer, therefore, may decide to certificate an engine for ethanol, methanol, methane, diesel, or some other fuel at his option. The same is true for an aircraft manufacturer; he may seek a certificate for a new fuel without assistance from the engine manufacturer if he wishes, but he would need to supply the demonstration. And an individual aircraft owner could do the same thing at his option. For example, a natural-gas pipeline helicopter operator might certificate its equipment to operate on liquid methane, with or without participation by the helicopter or engine manufacturers.

Certification for experimental operation is easier to obtain than where the public safety is at risk; certificates for commercial passenger operation carry the most comprehensive demonstration requirements.

But the important fact is that the Government does not prohibit application for any combination of engine/airframe and fuel. On the other hand, aircraft may be flown only with fuels which meet specifications for which they have been certificated.

The best long-term solution for general aviation may be to design future reciprocating and other engines to operate on jet fuel. Some aircraft engine manufacturers have adopted that goal, although solutions are not yet in sight. Operators of small aircraft, particularly those which use 80 octane aviation gasoline, are hopeful that automotive gasoline may be used in aircraft engines.

Mogas in Aircraft

Great Britain is likely to permit the use of automotive gasoline or mogas in small aircraft operations, but the situation is more difficult in the U.S. Because of diversity in climates and altitudes, U.S. mogas is conventionally blended for seventeen different markets in this country and changed with the four seasons. An aircraft which could use a certain mogas blend in a given locality or at certain altitudes, might find that fuel unsuitable at another destination or at points along the flight path.

Avgas is produced to more definitive specifications than mogas, since aviation requires more peak performance reliability, altitude restart capability, and other qualities. Because avgas characteristics are tested before it leaves the refinery, distribution of avgas must assure that these qualities are preserved. Except where an airport may be very close to a refinery, avgas is never pipelined because of the small quantities involved. If avgas is handled in a barge, tank car or truck that is not reserved for avgas exclusively, it may require retesting before it can be passed on as avgas. If this retest is demanding, as for octane rating for example, it may be necessary to ship a sample back to the originating refinery.

The cost of avgas is increased further because, while only a half-dozen or so refineries in the U.S. produce it, none of them runs avgas continuously. Thus, four or five days' shut-down may be required to prepare a refinery for an avgas run. A five-month's supply is then produced in only a few days. Several more days may be required to reconfigure the refinery for standard operation. The avgas output is naturally charged with most of these costs. Distribution also departs from standard mogas operations.

Mogas specifications are less exacting to begin with, while its handling is far less controlled. Protection from water, rust, dirt and other contamination is usually dependent on the interests and reputation of particular distributors and retailers. While avgas-handling facilities are regularly inspected, mogas facilities are maintained according to their owners. As avgas distribution decreases in volume, there is less incentive for distributors to maintain the equipment and care that they did as a matter of course in the past.

It has been suggested that quantities of lead-free mogas could be produced to avgas specifications in large batches without significant increase in cost. If so, appropriate quantities of those batches could be diverted to avgas distribution and, as long as maintained with avgas handling integrity, could be entirely suitable as avgas. After being assigned into mogas channels, the remaining gasoline in the run would not be used as avgas.

Refiners have commented that this concept may not finally provide aviation fuel at a better price. It may take time before the concept is resolved, favorably or unfavorably. In the meantime, at least one GA aircraft manufacturer is proceeding toward a Supplemental Type Certificate (STC) to operate one specific airframe/engine combination on mogas. As it is being pursued, however, the STC would permit operation with mogas only for recreational flying. No commercial operation — flying for pay — would be permitted under the STC.

If resolved for the 30% of U.S. GA aircraft which use 80-octane avgas, a problem still remains with the two grades of high-octane gasoline: 100 and 100 low-lead (100LL). Some engines have been developed for low-lead operation to meet emission standards or for other purposes, originally with the intent that 100LL could be used for all high-octane aviation engines. But it turned out that some engines designed to operate on leaded fuel require the lead for proper operation. Further, some low-octane engines which had been hoped to operate on 100LL, found that it still contained too much lead.

Thus, if low-octane engines can accept the new mogas/avgas and all others can use 100LL with suitable additives, the aviation gasoline problem will be significantly improved.

GA will still be concerned with aviation gasoline supply problems outside the U.S. Prior to the Iran-Iraq war, the formerly British Petroleum refinery at Abadan, Iran produced about one-third of the aviation gasoline in the world. With that supply cut off, the entire Middle East-Africa-India supply system has been disrupted. Whether and how this supply is restored is a matter of conjecture. While it may not affect GA operations within the U.S. directly, it has already depressed U.S. GA aircraft exports and might be expected to affect the used-aircraft market to some extent. This sort of experience with foreign sources should further stimulate U.S. GA engine and airframe manufacturers to look toward middle-distillate fuels.

The Electric-Powered GA Aircraft

Strange as it may first appear, there has been interest in industry as well as in technical literature toward electric power for GA aircraft. A first reaction would be to question the system's power-weight density because electric motors and electric power sources have traditionally been very heavy.

The aviation concept has been derived from light-weight electric motors and fuel cells successfully developed for marine torpedoes. As explained by Nigel Moll in ***Flying***,[9 12]

". . . how about a Bonanza powered by a torpedo's electric motor, lithium and hydrogen peroxide? That's what Don Galbraith, a missile expert with Lockheed Missile & Space in Palo Alto, California, is working on. At the moment, the electric Bonanza is still on paper, but Galbraith has done a stack of sums that show his project will work."

"Basically, his paper envisions removing the 205-hp piston engine of an early Bonanza and replacing it with a direct-current traction motor weighing 100 pounds and developing 205 hp for takeoff." Both hydrogen peroxide and lithium have presented operational problems in the past, but these problems need not be repeated in the aircraft system.

Galbraith indicates[9-13] that performance of the electric-powered airplane should be comparable to its conventional counterpart, independent of air density. That means it should have no power fall-off with altitude. In-flight reliability should be higher, cost per unit energy should be higher, but Galbraith concludes that cost per mile of travel should be roughly equal, other costs should be lower, and emissions, noise and safety should be improved.

The question seems to resolve significantly to the anticipated cost of lithium, costs of fuel cells, and the distribution and servicing costs for lithium and hydrogen peroxide. There is at least interest at the General Aviation Manufacturers Association (GAMA) that this might be one avenue to reduce GA reliance on avgas.

The prospects for low-priced lithium or fuel cells do not appear promising. Laboratories developing fuel cells advise that their costs and weight are expected to be too high for ground transportation for another ten years.

Nuclear Powered Aircraft

Although there is no apparent published interest now in nuclear-powered aircraft, a few words are offered here either to lay the subject to rest or to dilute any latent interest.

This author was responsible in the Convair General Office for reporting concept and progress of two nuclear-powered aircraft projects which were active concurrently during the late 1950s. A San Diego Division contract with the Navy studied designs of nuclear-powered seaplanes and their operating bases. The other, much larger effort, was a two-fold Air Force program in the Fort Worth Division. Comparable to the Navy program, one Fort Worth project engaged in design and operational studies of land-based nuclear-powered bombers. The other project involved installation and flight-operation of a small nuclear reactor in a B-36 airplane, together with all the servicing, flight and maintenice facilities and procedures required for that operation.

The B-36 project achieved its goals; the airplane was flight-tested, the reactor was run to criticality, and the airplane and reactor were maintained as planned. As would be expected, the B-36 airplane was extensively modified to provide radiation protection for the crew and to contend with radioactivity exposure of all the components and materials in the airplane.

The Air Force and Navy programs encountered comparable problems. High power output from the airborne reactors demanded heavy shielding for the crew, not only from direct radiation, but also backscatter from the surrounding atmosphere. Aircraft materials could become so radioactive that maintenance demanded very special facilities, techniques and scheduling. Maintenance areas were located literally miles from other operations. Because of residual radiation and limitations on shielding weight in the airplanes, handling of crew members and maintenance personnel presented major problems.

Safety and exposure standards then may not have been as stringent as today. It was concluded then that safety problems and costs would be immense. The consequencies of a crash were prohibitive at that time. Aircraft structure cannot be built to withstand crash loads. Crash loads are in an entirely different category than effects of earthquakes and other natural disasters on electric power-station reactors, contingencies which now stimulate much adverse public reaction.

It appeared that a large land area surrounding a nuclear aircraft crash might not be penetrated for years or inhabited for centuries, certainly conditions which could not be tolerated if a crash occurred in a populated area.

Further, nuclear propulsion appears to suffer an inherent technical disadvantage. The performance of any turbine is a function of its working-gas temperature range. In an internal-combustion (I.C.) turbine, its highest temperatures are in its combustion gases; the metal parts of the turbine can be and are cooled (usually by compressor-bleed air). Combustion gases are the working fluid. In a nuclear powerplant, heat is generated by fuel confined within metal and is conducted to the working fluid. That is, some metal must be at higher temperatures than the working fluid.

Since metal temperatures generally define performance limits for turbines, the working fluid of a nuclear-driven turbine must be at a lower temperature than for an I.C. turbine, and its power output is lower. In both Air Force and Navy studies, the aircraft burned hydrocarbon fuel to boost power up for takeoff, high-speed dash or other high-power operations.

This author has seen no suggestions in nuclear technology that might make military missions practical. There appears no possibility that nuclear-powered commercial aircraft will enter the picture.

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Chapter 10

Alternative Ground Fuels and Energy Sources

Board Room Briefing No. 10

1. The primary concern of this chapter is alternative fuels in aviation. But alternative fuels in other areas, such as ground transportation, should affect aviation fuel prices and availability far more than developments in aviation. Methanol, and compressed or liquid methane, are well suited for automotive power and promise lower costs. It is a chicken-and-egg proposition. Vehicles cannot be marketed without a fuel distribution system. The system cannot be financed without existing customers. Progress in this direction could revolutionize the entire petroleum market. Aviation would be swept along with the tide, falling heir to some of the displaced petroleum.

2. While most trends in the automotive arena appear favorable to aviation fuel prices, expected increase in diesel demand may deserve concern. Diesel power in automobiles is at a delicate waypoint. The diesel cycle is more efficient than gasoline, but may be unable to meet future pollution standards. Since its main advantage is compression ratio, it is vulnerable to replacement by methanol or methane, which permit improved, higher-compression, spark-ignition engines.

3. Investments in renewable energy plants and even synthetic plants enjoy an advantage over conventional oil and gas investments. Once the facility is in place, the resource may be practically or literally inexhaustible. For the life of the plant, production should remain at a constant rate, undiminished, and, with production costs largely a function of initial investment. The investment is a good hedge against inflation.

4. Synthetic fuels which rely on renewable feedstocks will find it difficult to compete in the market, except in unique economic, political and local situations. Quantities of feedstock required are so vast that only fossil sources appear capable of meeting the large demands at reasonable costs. Supplies of various fossil energy sources promise to meet man's needs for several generations.

5. In general, energy forms which depend on relatively diffuse renewable sources, and for which the cost of energy is at or near zero, require more total capital outlay per Btu or per kilowatt than processes which use fossil resources. It appears that these sources (forms of solar energy, etc.) often cannot compete directly in price. While these forms of energy will doubtless fulfill significant local or regional roles where they enjoy concentration, availability, economic or political advantages, they are unlikely to affect the world or U.S. national fuel price situation significantly for two or three generations.

6. The author notes that varieties of "renewable" U.S. energy sources, such as geothermal for one example, which compete with petroleum prices, do so because they are assisted by favorable taxes, regulations and financing (sometimes with tax-free bonds). Geothermal power, which is popularly (but incorrectly) regarded as renewable, receives depletion tax allowances.

7. If U.S. natural gas alone, or EOR and possibly other fossil sources were relieved of disincentives, even without the addition of incentives such as some other energy sources enjoy, this author believes that the entire U.S. energy picture and possibly that of the world, would be rescrambled.

8. Synthetics will find survival difficult if the world returns to further generations of cheap and plentiful fossil energy. If the U.S. takes no action, this situation might still develop with the U.S. as a follower, as it is today, rather than as a leader in world energy.

Originally, this chapter had been expected to be the longest in the report. It was thought that, in order to compare the resources, energy levels, costs, conversion possibilities and other characteristics for the gamut of energy and fuel forms, nearly all candidate and predict when and under what circumstances it evident that such an approach is neither necessary nor desirable.

Economists have stressed previously and experience has now borne them out: it is unnecessary to laboriously evaluate each candidate and predict when and under what circumstances they will enter the market. The energy market, where it is a free market, is dynamic and self-adjusting. The significant fact is that much energy is available in various forms.

As prices change or as production costs change, different energy forms will enter and leave the market. Relatively, it is not too difficult to distinguish those which are competitive or are nearing competitive standing. As long as the top candidates have resources great enough to survive for an extended time, the less favorable economic candidates further down the list assume less and less importance.

With the conviction that petroleum will be available for many years, that EOR and natural gas could extend that time considerably, that oil shale can provide liquid fuels for centuries, closely buttressed by coal, lignite and peat, there is no need to evaluate less promising candidates in detail. They must be evaluated enough to judge their relative status and to consider possibilities that might catapult them into the foreground.

This chapter considers only those fuels and energy forms which either have early promise or which have attracted popular interest. Volume 2 reviews all these candidates, and many others, in more detail. But Volume 2 presents them more for

interest and for long- to very long potential than for any probability that they will affect aviation in the next several generations of aircraft

Alternative Automotive Fuels

Despite the promise of oil shale for synjet production and recent success in that direction, developments in alternative automotive fuels could have greater effects on the future of aviation fuels. If alternatives to gasoline back significant quantities of petroleum out of the automotive market, jet fuel prices could drop immediately and quality could change. If demand builds rapidly for diesel fuel or for other middle distillates, the price of jet fuel could rise accordingly.

Unfortunately, with fuel now such a large component of airline operating costs, it is questionable how airlines will fare in a rising market for middle distillates. Aviation publications increasingly report airline problems with fuel cost, particularly as fare competition becomes sharper. At the same time, the value of older aircraft with their lower fuel efficiency, has fallen rapidly in the used-aircraft market, while airlines are canceling orders even for new, fuel-efficient equipment. There is increasing speculation about airline bankruptcies and mergers.

There may be little that aviation can do about the automotive fuel future, but it is well to consider some of the consequences.

Gasoline and diesel fuel perform well as automotive fuels and the incentive for alternatives resolves to the familiar subjects of reliable availability and lowest price. With achievements in conservation during the recent past and continuation expected in the future, the fuel demand outlook has improved rapidly. Further improvement in automotive fuel mileage may be expected. Substitution of coal for petroleum in stationary powerplants, for generation of electricity, and particularly proliferation of cogeneration systems, is expected to depress the petroleum market further.

The American Gas Association is rightly concerned that, with continued restrictions against use of natural gas in generating electric power and in industrial processes, natural gas demands will decrease. Home insulation improvements, replacement of old furnaces with new pulse-combustion furnaces (which are equivalent to increased compression ratio), significantly improved heat pumps, and alternatives such as solar hot-water heaters, will continue to make inroads. As many have observed, even if fuel prices remain stable or decline to some extent, the new efficiency trend has been established; newer methods and equipment will continue this invasion. Customers are not likely to return to the inefficient models, while older equipment will be replaced with more efficient designs. All this additional conservation should benefit aviation.

Of course, if natural gas, enhanced oil recovery, peat or other large sources of energy are permitted to develop competitively, fuel prices could be depressed even more dramatically. First, we will have a brief look at automotive fuels.

The major alternatives for replacing automotive gasoline appear to be propane, methanol, compressed natural gas, or liquid natural gas. Details are reserved for Volume 2; the summary here will be short.

Propane

Propane offers some distinct advantages in automotive equipment. It produces less emissions and, particularly in confined areas such as factory buildings or warehouses, can be used without producing toxic carbon monoxide. Propane is a gas at atmospheric pressure and room temperatures, so it is stored as a liquid in pressurized tanks at up to about 200 psi. As released to the engine, it does not have the vaporization problems of gasoline. An engine starts cold easily with propane and does not require a richer mixture during warm-up

Its laboratory octane rating is about 112 and motor octane rating about 95, so it has excellent anti-knock characteristics in current automotive engines. Its price varies with geographic locations, but in the U.S. in mid-1982, it runs generally less than 75 cents per gallon. A gallon holds 25-30% less energy than gasoline, although being a light-weight fuel, it holds more energy per pound

In addition to many industrial trucks and tractors in the U.S., propane is used in Canadian automobiles to a fair extent. In the U.S., Ford has indicated that they may offer propane cars for fleet operation and possibly for private operations. The major problem for a private operator would probably be the availability of fuel

Other than availability, handling safety may be the second consideration. Since the liquid is under pressure, it must be handled more carefully and the equipment must be maintained reasonably. But the 200 psi-and-under pressure for propane does not compare with the nearly 3000 psi of compressed natural gas (CNG). And CNG has been used safely for many years in Italy

As far as supply is concerned, propane offers no long-term advantage over gasoline. It is produced with gasoline as one of the "natural gas liquids," which includes butane and others. The present advantage of propane is that it is in less demand than gasoline. Presumably if the demand for propane increases, like the rise in price of diesel fuel, propane may be expected to index to gasoline prices. If the U.S. demand for propane increases appreciably, we will find that more propane must be imported.

For automotive use, the liquid petroleum gas (LPG) which is sold as propane must be about 90% propane. Butane has a low vapor pressure and does not start at low temperatures. About 5% of the 10% not propane may be isobutylene. But the remainder may be no more than 5% propylene, an olefin with poor octane characteristics.

Because natural gas liquids, or LPG is normally a small fraction of the petroleum product, the total potential of natural propane in automotive use is inherently limited. There appears to be no advantage in synthesizing propane, for example, in an automotive market which is already geared to gasoline. Like New Zealand, their large supply of natural gas can be synthesized to gasoline

Of course, again since aviation is such a small fraction of the petroleum market, if the propane fraction were substituted for some of the petroleum, it could assist the aviation supply

Methanol

Methanol can be produced from coal, more easily from natural gas, or from any hydrocarbon source, including biomass such as agricultural and industrial wastes, wood wastes, garbage, feedlot and sewer wastes. Methanol, or methyl alcohol, "wood alcohol" can be used directly as automotive fuel or as an octane enhancer for gasoline, as ethyl alcohol is being used in Brazil to make gasohol

Incidentally, with the rising world price of sugar, it is understood that Brazil is now trending more toward "alcogas," or a larger percentage of gasoline in the mix. Ethyl alcohol is too expensive in most of the world to be used directly as fuel. Brazil may be finding that adverse economics apply there as well. Production of ethyl alcohol usually requires diversion from the food chain. Many analysts have concluded that ethanol production requires as much or more net energy than in the ethanol produced. IIASA [illegible] concluded that foodstocks will remain too valuable to be used as fuel feedstocks

But methanol appears to be price competitive and to have extra value in reducing the disposal costs of unwanted wastes. Methanol can be produced from biomass and fibers which can not be converted to feedstocks. A September 15-16, 1981 seminar of automobile and powerplant manufacturers, oil companies, chemical producers, energy specialists and financial institutions arranged by the Mellon Institute [illegible] concluded that widespread use of methanol as an automotive fuel is inhibited mostly by the chicken and egg situation. Methanol powered vehicles are unlikely to be marketed until a distribution system is available. Financing a distribution system is dependent on ready demand by methanol vehicles.

This problem is, of course, common to any alternate fuel situation.

The situation is also aggravated by limited production of methanol in the [illegible] methanol is produced today. [illegible] could be increased ten or twenty fold by the [illegible] competitive with projected oil prices.

The seminar concluded [illegible] that technical issues pertaining to the use of methanol in the automotive fleet are either solved or their solutions can be easily established. [illegible] It poses no extreme problems to humans or to the environment and, except for the need for prevention of ignition of vapors above the liquid level in the tank, presents no flammability or explosion hazards not encountered with gasoline. While neat methanol appears to present no engine problems, manufacturers were concerned about use of blends which offer no performance or economic advantages. No institutional barriers were identified. Effects on lubrication were regarded as needing further work, but not [illegible] as insoluble problems.

It was concluded that the methanol market will develop when the parties have sufficient motivation. Motivation might include lower costs, avoidance of octane problems, fuel economy, performance, air quality improvement, and reduction of oil imports.

Some of the greatest concerns were about potential antitrust violations in attempts to solve the chicken-and-egg syndrome, the need for a national petroleum pricing policy, for emission standards, for tax credits and government purchases. In this case participants were particularly mindful of the recent Brazil experience where an inability of the government to adhere to pledged price and quality commitments has resulted in serious reversal of the vehicle market place.

There was considerable concern that a uniform national system might not evolve, particularly due to regional interests in blended fuels, dual-fueled vehicles, or other variations. Options in distribution systems, fleet operations and other details were found to be significant.

The seminar looked at the situation from today's automotive base, considering the automotive market as an entity. It may be equally pertinent to consider the world or the national outlook for methanol as a petrochemical feedstock, followed by its application to the automotive market.

As OPEC countries and others develop capital from oil production income, they are almost certain to cease or decrease flaring natural gas. Capital will be invested in gas-to-methanol or gas-liquefaction plants, and markets will be sought for their output. Developments such as these could have a significant effect on both the price and distribution of methanol. In turn, increased use of methanol as a fuel or as a feedstock will soften the petroleum market, trickling on down to aviation.

Compressed Natural Gas — (CNG) and Liquid Natural Gas — (LNG)

Both CNG and LNG have been discussed earlier in the report and are covered further in Volume 2. Summing it up for automotive use:

CNG — Used fairly extensively in Italy since WW II, the natural gas is compressed to about 2750 psi. Italy produces special automotive CNG tanks which are lighter in weight than the typical compressed-gas bottles used in the U.S. Italy has also developed standards and techniques to be used at filling stations. Their safety record has been extremely good and New Zealand questions whether the Italian standards are undesirably high. But CNG tanks are still relatively heavy and the volume of CNG which can be installed in a car is inadequate. Autos and trucks powered by CNG typically have ranges of less than 100 miles.

Perhaps one attractive option for CNG is that, with a small home compressor unit in the garage, believed costing less than $100, it is possible to refill the auto tank from the household natural gas supply line. Otherwise, requiring up to 3,000 psi, refills at filling stations are from pre-charged bottles to avoid the long fill times. Instead of large gasoline storage tanks, commercial public CNG filling stations use banks of bottles which are recharged relatively slowly.

As has been mentioned, New Zealand is short on other hydrocarbons, but has an abundant supply of natural gas. They have analyzed the natural-gas-to-automotive possibilities more than any other group in the world, starting with an intensive evaluation of CNG experience in Italy.

Natural gas operates very well in existing cars, the question is how to transport it and store it in the vehicles. CNG offers the advantage of early use, with fairly mild distribution and capital investments. Hence, New Zealand is promoting CNG as a short-term relief to petroleum imports, largely for fleet-type operation. While they are also offering it for private automobiles and have opened a few government-owned stations, CNG is not catching on well with distributors or motorists.

New Zealand considers their final solution is gasoline synthesized from natural gas by the Mobil M process, which is under contract and in construction. The capital expenditure and conversion efficiency for gas-to-gasoline are important, culminating in the final price. It is expected to be competitive with natural gasoline and, when in full swing, hoped to be cheaper in New Zealand.

LNG — New Zealand is also looking to LNG because of the longer vehicle range it permits over CNG. An LNG automobile is essentially directly comparable with a gasoline-powered car. The octane rating of natural gas is about 120; it is completely vaporized and well-mixed with air and, like LPG, has no cold-start or rich warm-up problems. An LNG car would like a somewhat larger fuel tank than for gasoline because LNG has less energy per gallon. But, because it has good cold start and lean-start characteristics, fuel air mix, etc., some users report miles per gallon comparable to gasoline, particularly for short trips.

Because methane contains more energy per pound than gasoline, the fuel system for an LNG car weighs no more than for gasoline, even with the cyrogenic insulation. A gasoline-powered car can use CNG or LNG satisfactorily as an alternate fuel. The car requires separate fuel systems and a gasoline carburetor, of course, but dual fuel systems are operating in which the driver simply uses a selector switch on the dashboard.

The major drawback to LNG is the cryogenic fuel and its required insulation. Liquefaction equipment is generally expensive and the liquefaction process is costly in energy. Even so, LNG sells for around one third the cost of gasoline in the U.S. At the present time, LNG is being used in some U.S. vehicle fleets and the prospects for more applications are bright. Again

facing the chicken-and-egg picture. LNG is a completely legitimate candidate as the primary national automotive fuel, as is methanol.

The question is whether gasoline will continue to be plentiful and affordable, whether gasoline synthesis from natural gas is economical, whether methanol plants will proliferate for petrochemical operations, stationary powerplants and transportation, or whether small methane liquefaction plants become economical and LNG takes over.

In a typical cyrogenic automobile tank, LNG begins to boil off after about ten days, and then at a rate of about one cubic foot of gas per hour. That gas could be vented into the household natural gas supply system or released to the atomosphere outside buildings. If a small, economical liquefaction unit is developed which can refill the car's tank overnight from the household gas line, then LNG could become very attractive. It would appear to offer many of the advantages of electric automobiles, without many of their disadvantages.

Electric Vehicles — Electric road vehicles are reviewed further in Volume 2. Here, the conclusions are summarized briefly.

Batteries have been developed for more than a century and their technology is well known. The likelihood of major breakthroughs appears very small. Electric cars do not appear to be able to break the 100-mile range barrier at reasonable costs. As it is, batteries make up typically one-half the weight of the automobile.

They are also typically one-half the cost of the car. The number of recharges possible has a discrete limit and, with normal use, batteries last from three to five years. Not a very attractive economic picture for the private owner.

Being heavy, the cars have sluggish performance. Although their speed is generally low, aviation personnel will be interested in why they are usually streamlined with sophistication. Although the speed is low and the drag is also fairly small, ***power is so marginal that a battery-powered car needs all the aerodynamic help it can get!*** The situation merely emphasizes how desperate the weight penalties must be.

The main virtues of electric cars are that they use no power while stopped in traffic, while they may be recharged from the municipal electrical system. As the IIASA study[4.5] concluded, electric cars offer no panacea for world or national energy. They must be re-charged in off-peak electrical load periods to make any sense at all. Additional electric generating power installed and operated in a community to recharge electric cars is highly uneconomical both in energy and in dollars.

In a community of about a million population, the electrical system would be able to service off-peak about 100,000 vehicles. So electric vehicles should never become the major transportation mode in any community.

When fuel cells become lightweight and economic enough for vehicles, the range and weight of an electric car could be released from its battery bondage. Fueled with LNG or LH_2, the fuel-cell-electric car would be ecologically benign and much more energy-efficient than a battery-powered vehicle. It appears attractive as a component in the "hydrogen economy." But, if powered by LNG or LH_2, at least in the near future, internal combustion engines could use the fuel and power the vehicles at lower cost.

Alternative Energy Sources

In preparing for this report, an effort was made to explore every potential source and form of energy which could have a bearing on aviation, directly or indirectly. With aviation such a small percentage of the market, it turns out that almost any appreciable energy potential or development could be important. Consequently a wide variety [illegible] was reviewed, enough to select those which would affect aviation the most. Many of them have already been discussed in the course of this report.

It had been intended to review each energy area, to assess its potential and to show how it might affect the future energy market. Originally, it was thought that comparison tables or charts would be useful to indicate how competing energy components might emerge. The idea was to present how long oil, natural gas, coal and other hydrocarbons might last, how nuclear fission, hydroelectric, geothermal and other sources might provide a transition, and how a final combination of solar energy and nuclear fusion (or whatever) might end up serving the world's needs.

More understanding of energy and the energy market brought complete changes in concept. It has been interesting for this author to note that in the popular press as well as in technical, economic and other professional papers, how significant changes in concept have occurred over the past few years and then over the past few months. The first major realization is that, while we must inevitably run out of oil, the time is not soon and the alternatives are legion.

Before 1973, oil sold below its replacement value and the world economy was based on that [illegible] much low-cost oil was available that high [illegible] compete. Then OPEC and other suppliers recognized that market demands were rapidly approaching the world's production capacity. Seeing that the marginal costs of new production were so much higher than production costs of old oil, OPEC raised prices until the replacement cost level was [illegible] in the market.

Now that world oil prices are consistent with marginal replacement costs and the world market is near a supply-demand balance, many earlier energy [illegible] assume little importance. It is clear that there is so much fossil fuel available in various forms that the question is simply how the market demand will develop and what fuels or energy sources will be able to compete in the market as developments and price changes take place.

These questions are far from insignificant, however, because answers determine how investments will be made, how the economy may prosper or lag, our vulnerability to foreign fuel supplies, and the like.

Instead of a comprehensive and [illegible] comparison (which would also depend on assumptions made), it may be more useful to set down summary remarks about some sources and forms of energy. Some of these will become indirectly important to aviation. Others are included for their possible interest and perhaps to lay some [illegible] to rest. All are discussed in a more organized and comprehensive format in Volume 2.

Geothermal Energy

For discussion, geothermal energy may be a strange first choice. But it was in a session on geothermal energy that a strong realization emerged [illegible]. The meeting concluded that geothermal energy in the steam or vapor phase competes economically with steam electrical generation by coal and nuclear power, but that liquid phase geothermal sources could not compete. (Liquid phase geothermal sources could compete for industrial or space heat purposes, but not for electrical generation.) The comment was made that, with additional tax benefits or other favorable regulations, liquid phase geothermal sources might also compete in electrical generation.

So far, only one vapor phase geothermal source is proven in the U.S.: The Geysers in northern California. It is, by far, the largest geothermal installation in the world. A second source has

been tested in New Mexico, but is not yet known to be of commercial stature. All the other geothermal areas in the U.S. and most in the world are liquid-phase or dry heat. In a dry-heat source, water must be provided for conversion to steam, an appreciable cost item. At the same time, through its popular reputation as a "renewable" resource, geothermal power has gained special tax and other privileges.

But The Geysers is already enjoying special federal and state benefits, ***including depletion allowances for a reputedly infinite, renewable resource***. The depletion allowance is actually rational because geothermal sources really are depletable. New wells must be drilled periodically, their production rate is limited and declines with age, and sources have finite life spans, perhaps comparable to oil or gas wells. If so, and if oil and gas fields offer a greater potential to the national economy and our potential relief from foreign oil disruptions, why should special advantages be granted to these limited resources, which can serve only a very limited part of the country?

Instead of granting more incentives to subsidize localized energy such as geothermal sources, it appears the national welfare would be better served by removing some of the disincentives from EOR and natural gas, for example. This principle may be equally applicable to other types of energy with limited national potential.

Hydroelectric

Most of the large U.S. hydrelectric potential has already been exploited, although another 15-20% increase may be possible [10.3]. As has been popularized, some small installations may be refurbished or rebuilt for contributions to local communities, but not on a scale significant to the nation's total energy.

In the world, a fair amount of potential hydroelectric power remains undeveloped. But studies and experience with dams such as Aswan have shown that hydroelectric power is among the most environmentally disruptive of all types of power. Perhaps more significant, the IIASA concluded that the Less Developed Countries could not afford and the industrial countries could not provide them with electrical distribution systems. According to IIASA, if the industrial countries donated nuclear powerplants to the LDCs, electrical distribution could not be provided. Presumably if hyrdoelectric plants were provided, the same distribution problems would apply.

Nuclear Power

Nuclear power probably falls within the descriptions outlined just above. In either a breeder reactor, in a system with a fuel-recovery cycle, or presumably in a fusion power cycle, the cost of fuel is essentially negligible per unit of power produced. Major costs are in the plant facilities. At present, regulations, restrictions, legal delays, uncertainty about safety requirements and other unknowns have clouded the facility costs and construction schedules for nuclear plants. The near term problems do not appear to be technical, but political.

Nuclear fusion may not hold out the promise that is popularly supposed. The chances of success with fusion seem to be growing. But it is already evident that fusion plants are likely to be as expensive as fission plants and that the shield material and by-products will likely present radiation hazards and disposal problems comparable to fuel in the fission reactor.

Many studies conclude that, as petroleum production declines, we will seriously need nuclear power along with coal and other sources to supply the world's and the nation's power requirements.

Early expansion of nuclear power seems to be delayed so that we may not expect it to contribute much to replacing petroleum in the stationary power market. We must hope that oil and gas production will continue without serious decline until our nuclear affairs are resolved.

Solar

Most students of energy now categorize all solar type sources together. In addition to solar collectors and reflectors, this grouping should properly include OTEC, salt ponds, windmills, hydroelectric, waves, ocean currents, and even exploiting the differences in water salinity near river mouths. This author agrees. It is only for convenience in considering economics and competition that the pattern has been broken here.

Ocean Thermal Electric, Salt Ponds

OTEC and salt ponds have an advantage over other solar-derived energy sources in that they may operate around the clock. But, more than liquid-phase geothermal, they suffer from low temperature differences and resulting low thermal efficiencies. While the sources may be large, very large facilities and equipment are required to extract the low-level energy at a significant rate. OTEC and salt ponds are like a hydroelectric source with a very small head of water.

Another illustration was drawn from the geothermal session. The USSR operated a liquid-phase geothermal source on the Kamchatka Peninsula to see if it could produce electricity economically. They expected the generally cold atmospheric temperature would assist the thermodynamic cycle, which it no doubt did. But it was concluded that the output from a full-scale plant still could not justify the investment required, and the project was abandoned.

It is probably valid to conclude that, even with an effectively infinite or free source, energy can be competitive only when the capital facilities are somewhat comparable to those required for fossil-powered plants. An economically feasible free, renewable or unlimited source must have concentrated, not diffuse energy. Otherwise it takes too much hardware and installation for conversion to a usable form.

OTEC may be competitive in special locations like Hawaii and Puerto Rico, where low-temperature deep water, relatively high-temperature surface water, and a population of consumers are in close proximity, without serious competition from fossil sources. Even so, the size of the plant investment and its maintenance may rule against OTEC. The present concept of cleansing marine growth from mammoth condensers with acid or special devices may throw such a system into the uneconomical category.

Similarly, salt ponds may work well in the Dead Sea area or in the U.S. Imperial Valley. Again, details of operation, when translated to commercial size, may uncover insurmountable obstacles. In both cases, the opportunity appears small on a national or world scale.

The idea of OTEC ships slowly "grazing" the tropic seas to avoid recirculation of used water, appears doubtful because their energy must then be re-converted from electricity to a portable material such as ammonia, methanol, liquid hydrogen, fertilizers or other energy-intensive commodity. It is expected that much smaller plants on barges or ships can tie up where natural gas or gas terminals will be available around the world and that, for decades, plants of that type will be able to produce the same products at lower costs than OTEC.

The question is more apt to be whether these smaller plants can compete with large, stationary ammonia, methanol or hydrogen production plants which major oil and gas producers are likely to bring on stream. OTEC would not appear viable in that sort of open competition. It needs the advantage of selling energy to an energy starved locale.

Wind energy may enjoy similarly limited and tenuous applications. Hawaii mountaintops have been judged the most favorable location, with the Aleutian Islands a distant second, because of weather and transmission difficulties. If windmills cannot compete on a large scale in either of those locations, there may still be opportunities for much smaller and localized installations. Although some may be important to local economies, the aggragate is not likely to affect the national or international energy pictures.

Harnessing ocean currents requires tremendous facilities, if feasible at all, while extracting really appreciable quantities of energy raises questions about fishing and climate effects. Both tides and waves are intermittent and very capital-intensive. Locations of opportunity are scarce. On a world or on a national scale, neither is likely to become significant. However, in a report on marine energy to the UN Department of International Economics and Social Affairs, Jacques Constans of the Cousteau organization recommends:(10.5) "(It is) . . . recommended that all countries having coastal engineering and/or harbor construction projects under consideration assess the possibilities of including in the forecasted structures some wave energy conversion system capable of easing their local energy requirements." He notes that several potential areas for tidal systems, including the Bay of Fundy, may become economical if fuel prices continue to rise.

Phillips of Johns Hopkins,(10.6) points out that the Bay of Fundy tides are large due to resonance, as are most large tides. The world's largest installation at the Rance River estuary in Brittany, France, provides only 500MW, about half the output of one modern coal or nuclear plant. Phillips notes that the entire U.S. potential of tidal energy could supply less than 1% of our national electrical needs. And, again, with a low hydraulic head, the turbines must be much larger than for high water heads, exclusive of all the dams, gates and other major parts of a tidal installation.

Other Solar

And so on with a variety of other concepts and variations. Most direct solar systems are productive for a maximum of about eight hours a day. Solar reflectors and photoelectric cells, if used in large quantities, require large land areas, deny the area for other use, and entail significant investments. IAASA commented(1.6) that if industrial countries could give LDCs free photocells, neither they nor we could afford the steel and concrete to install them on the required scale.

The solar space station concept has drawn interest from both space scientists and microwave specialists. The idea is to assemble a station in space, probably in stationary orbit, and collect solar energy on a nearly 24-hour schedule, free from atmospheric interference. Energy flux available in geostationary orbit is about 15 times greater than at the earth's surface. Solar power would be converted to microwave frequencies, transmitted back to an antenna field on earth, re-converted to electrical power and fed into a distribution grid.

An appropriate comment is that, if and when such a system can compete in the market with other options, then it should proceed. The problems are that costs cannot be estimated with any reliability until considerable preliminary work has been accomplished on many of the subsystem principles and components. Fundamental answers depend on the costs of launching and assembling the space station. Small differences in conversion efficiencies may lead to appreciable differences in size for the station, the antenna farm and other components.

While the system may hold some long-term promise with improvements, it does not appear to be a valid competitor in today's market or in normal future cost projections.

Various solar systems may compete in local energy markets and, in the very long run, the total may register on the larger scale. But applications are more likely to be in industrial process heat and space heat, not likely to displace fuels which would be used in aviation.

Coal

There are a few comments about coal which should be recorded because of its impingement on the total energy picture, with possible effects on petroleum and trickle-down effects into aviation.

First, nearly 90% of the world's known coal resources are located in only three countries: the U.S., the USSR and the PRC, People's Republic of China.(10.3) Of the remaining 10%+, half of that is in Europe. Coal being produced now in Australia, or the coal of South Africa being used at SASOL, the largest synthetic fuel installation in the world, are rare, local and limited phenomena.

Since early coal production was associated with the industrial revolution in Europe, it is a popular concept that Europe must be well endowed. On the contrary, Europe has little coal; most of it has already been mined. The U.S. should be able to assume the role of coal supplier to the western world.

Aside from mining and transportation costs, the two most difficult problems associated with coal are handling and emissions, including disposal of ash. In addition to gasification and liquefaction, there are other promising potentials for improving the use of coal.

Cogeneration of electricity and process heat, not peculiar to coal, is gaining more interest. Efficient generation of electricity requires high-quality steam. The steam turbine exhaust contains useful energy at a lower temperature. Since low-temperature process heat cannot be transported economically, powerplants generally cannot sell their discharge heat (hence cooling water and towers). Many industrial plants manufacture their own process heat. At a higher cost, they may also generate most of their electrical requirement, all of it, or excess electricity.

Depending on its needs for process heat and electricity, as well as the local price of electricity and other economic considerations, an industrial plant may find that it can more economically generate its own electricity or excess electricity which, under PURPA, the local utility must purchase at its cost for electrical power generation. Under these favorable conditions, cogeneration is receiving expanded interest.

Fluidized-bed combustion of coal has proved to be efficient in large installations and is gaining success in smaller boilers. Instead of support by a mechanical grate, coal burned in a fluidized bed is buoyed by a continuous blast of air or gases. Combustion efficiency may be improved but more important, by adding ground limestone, many of the exhaust stack impurities can be significantly reduced.

Fluidized-bed combustion should eliminate the need for expensive exhaust-stack scrubbing. That is, if present regulations are changed. Today, scrubbers are mandatory (the law says the latest technology ***must*** be used) in coal-fired plants, regardless of the type of coal burned or the efficiency of the combustion! Fluidized-bed technology may reduce perhaps the greatest obstacle to expanded use of coal. But it can succeed only if deregulation keeps pace with the technology.

Magnetohydrodynamics

Coal boilers are typically base-load components in electric power generation systems because of start-up times, massive material flows, and lack of flexibility for loan variations. Magnetohydrodynamics offers a possibility for rapid response to changes in load demands using coal as the fuel.

Since electricity is generated by moving a conductor in a magnetic field, when a current-conducting hot gas or plasma is moved in a field, electricity is produced. Conventional steam power plants operate at an efficiency of about 40% overall. ". . . an MHD generator has the potential for increasing the overall plant thermal efficiency to around 50% and values higher than 60% have been predicted for advanced systems."(10-4)

An MHD generator is a channel or duct in which plasma (partially ionized gas, that is, with some free electrons) flows at about the speed of sound through a magnetic field. High field strengths needed are supplied with super-conducting magnets. Electrodes for conducting current into and out of the gas are one of the major developent problems. The high temperature for ionization can be achieved by using oxygen or preheated compressed air for the coal combustion.

Conductivity of the plasma may be enhanced by "seeding" it with salts of potassium or cesium, which are extracted for reuse. The hot gas exhaust can be used for generating steam, and on down into process heat. Advantages of MHD are expected to be relatively low capital cost for power output, ability to come on line in about 5 seconds, control from no-load to full load in a fraction of a second, and lack of moving parts. Liquid metal can be used instead of gas; other heat sources such as nuclear fusion may be used.

In the U.S., effort has been focused on component development and high-temperature problems. Generators up to 30 MW have been operated for a few minutes. This technology has received strong interest in the USSR, where plants of up to 25 MW have been operated for brief periods. The outlook appears encouraging for MHD facilities to operate in electrical emergency and peaking use for about 100 hours per year.

Although MHD fuel consumption concerns a relatively small national quantity of fuel, its direct interest to aviation is that MHD may replace aviation gas turbines presently used for peaking and emergency standby in electrical generation plants. Here is a development which may decrease the market for aviation gas turbines, along with their demand for jet fuel (where they are not operated on natural gas).

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Chapter 11

Fuel Conservation in Aviation

Board Room Briefing No. 11

1. Most of this report discusses the supply side of the fuel supply/demand balance. This is the one chapter primarily directed toward the demand side.

2. Airline cash flow is dependent on maximizing seats and passenger traffic with minimum number of flights to serve the market. It is undesirable to reduce fuel consumption by reducing service. Most immediate fuel saving is through decreasing or eliminating unprofitable routes, trips and aircraft. Starting with the 1973 price rise, airlines have actively decreased their fuel consumption in these ways.

3. Since 1973, airline fuel costs have increased from about 25% of direct operating costs (DOC) to over 50% DOC. Less than 3% additional improvement in fuel consumption during 1980 would have eliminated the $286 million airline industry operating loss. If airlines had not already been pursuing fuel economy vigorously, their losses would have been much greater.

4. Airline deregulation and sharp competition have accentuated the airlines' problems. Some fuel economy is sacrificed intentionally to compete in flight frequencies, times, connections, and so forth. Nevertheless, since 1973, airline passenger-miles produced per gallon of fuel have increased by more than 50%. These savings were achieved primarily by higher load factors, increased seating density, better fleet mix and operating efficiencies.

5. These fuel savings are not particularly large, compared to the national or to the petroleum fuel pictures. They have not even impacted refiners severely. But they are vital to the economy of individual airlines. Airlines must master fuel economy now to compete and survive.

6. Load factors, seating densities and fleet mixes are considerations which cannot be generalized. Each airline must determine its optimum strategy based on its competition, available equipment, routes, financing, and other major operating factors. Deregulation has tightened the cycle, necessitating almost continuous re-evaluation: every day sets a new contest.

7. There are lists of fuel-saving items in aircraft operations and maintenance which airlines can consider according to their cost/benefit savings. Working up beyond the no-cost and low-cost procedures, fuel can be saved by re-engining old aircraft at up to 20% fuel economy, or buying new aircraft at 30-40% fuel economy.

8. Beyond the immediate generation of new aircraft coming on the market, additional fuel conservation still appears likely. Manufacturers seem confident that 30-50% additional fuel economy may be reasonable in at least the next two or three generations of aircraft — each 10 to 15-year period.

9. Air traffic control inherently requires fuel sacrifice since some aircraft must yield right of way. The U.S. Air Traffic Control (ATC) system has required more diversions and delays than desirable; automation has been postponed due to costs and labor objections. It now appears that ATC automation is fairly well assured and that improvements will be phased in steadily during the next ten to twenty years. These improvements will benefit all aircraft as they use the system.

10. Weather delays become very apparent during bad weather conditions. But additional appreciable fuel penalties are incurred when aircraft are flown inefficiently due to inadequate weather information. Technical equipment exists today and costs would be relatively trivial to establish a first rate, 4D, real-time, aviation weather system. The importance of these savings to airline financial survival is well understood at the working level. But sustained management attention and support in FAA, the National Weather Service and NASA will be required to equip the U.S. ATC system with the weather system it needs.

Activity Since the 1973 Oil Embargo

In 1980 the U.S. jet fuel bill was more than $11 billion; therefore, each 1% of fuel saving for the fleet was worth over $100 million in direct fuel costs. An additional fuel saving of less than 3% would have erased the airline operating losses of $286 in 1980. Despite increased attention and efforts toward fuel savings, a preliminary report [illegible] sets airline 1981 operating losses at $542 million, 90% greater than in 1981. The fuel bill had not yet been reported; it appears to be about the same $11 billion as in 1980. But it is painfully apparent that airlines must continue to pursue fuel conservation diligently.

Probably the two most powerful and immediate means to save fuel are by (1), increasing load factor — decreasing the number of flights for the traffic flow and (2), increasing the number of seats in aircraft — more seats closer together. These tactics are strongly affected by competitive market pressures.

There are other tactics which require no changes in equipment or new equipment, such as reducing the cruise speed of aircraft, reducing the fuel reserve carried, reducing the dead weight carried, and improved maintenance. It is interesting that airlines probably have made all the adjustments in cruise speed, other than conscious sacrifices to schedules and competition. As may be seen in Figure 11-1, the optimum cruise speed of a DC-10, at the given gross weight and cruise altitude, is about Mach 0.80. If speed is further reduced below 0.80, the miles made per 1000 lb. of fuel burned decreases, fuel consumption increases.

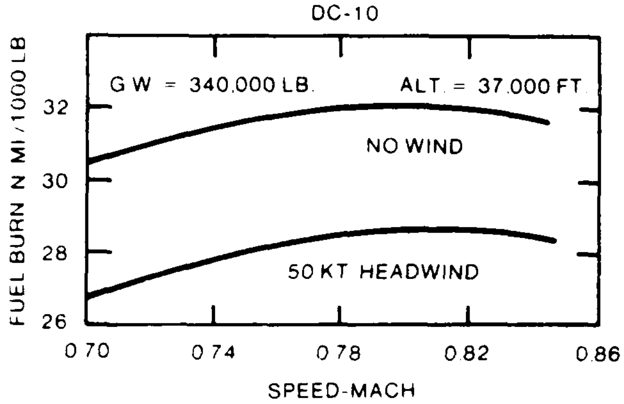

Figure 11-1
Effect of Cruise Speed on Fuel Burn

It is seen that the airplane is not greatly sensitive to small changes in cruise speed. On the other hand, a fifty-knot headwind at cruise altitude increases fuel burn by more than 10%.

Fuel conservation by reducing weight, including weight of tankered fuel, varies with range and mission. An average penalty for extra weight, however, is about 20% penalty for transcontinental flights. That is, it costs a pound of fuel to carry each extra five pounds of any weight. Weight reduction in existing aircraft therefore should receive continuous attention. In new aircraft designs, weight saving has always been important for performance, now fuel savings have assumed comparable importance and weight saving assumes an added component.

Similarly, drag has always been vital to range/payload and for schedule competition. Drag conservation and engine maintenance are even more important than weight conservation for direct fuel savings. Where a 5% saving in weight reduces fuel burn by about 1%, a 5% reduction in drag or a 5% improvement in engine performance, each would produce a 5% decrease in fuel burned.

Airlines have been selecting their flight altitudes and weather routing more carefully, have gone to fuel-efficient maintenance, have eliminated their less efficient flights and have grounded their less fuel-efficient aircraft.

In 1973, FAA and the airlines instituted a joint program to:

- Revise gate hold procedures; hold aircraft at the gate with engines unstarted when delays could be predicted downstream.
- Revise flow control procedures; hold or divert aircraft from areas of high congestion and traffic delays.
- Optimum cruise speeds; Consciously attempt to select and permit flying at best altitudes and speeds.
- Revised air traffic control procedures; better communication, fewer diversions for identification and procedural purposes.
- Taxi with fewer engines.
- More use of simulators instead of aircraft in crew training and checks, reduces the fuel burned directly, and air traffic where training would have been flown.
- Airport development, select facility and equipment improvements with more payoffs in decreased delays and fuel burned.

With all these efforts by airlines, ATC, and airline/ATC collaboration, airline fuel burn improved from 17.5 passenger-miles per gallon in 1973 to 25 PM/gal in 1979, for a 43% improvement. Air Transport Association data reported by Boeing are shown in Figure 11-2.

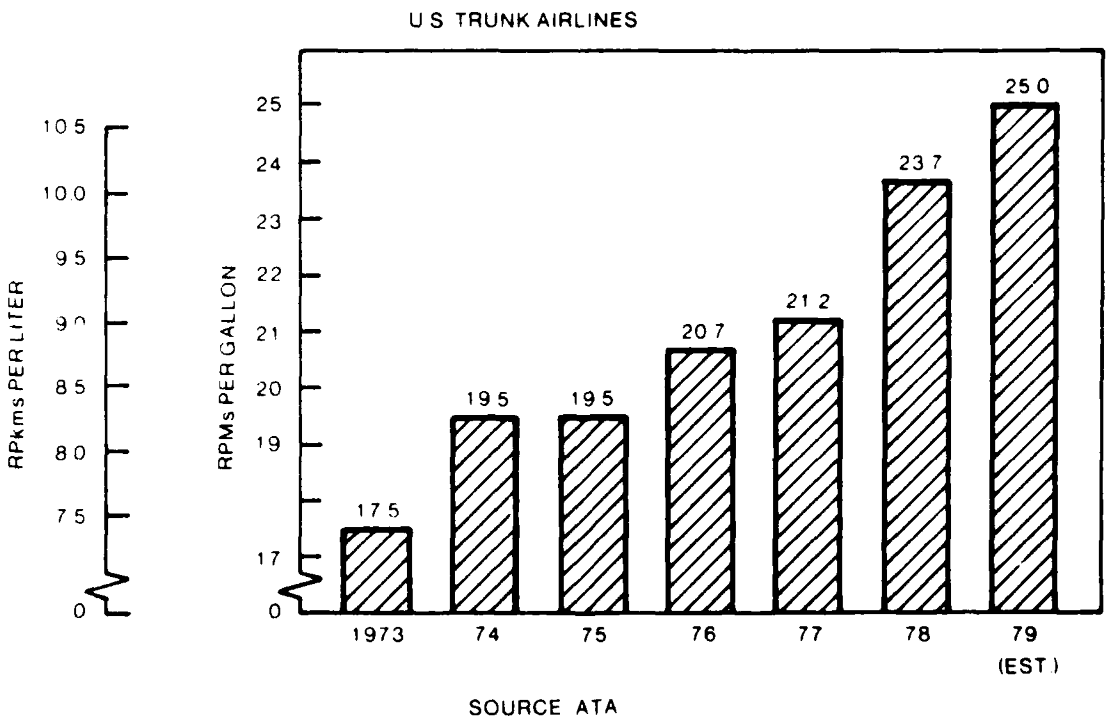

Figure 11-2
Airline Fuel Utilization

Fuel Conservation Progress

In addition to design of new aircraft and proposed modifications to improve fuel efficiency for existing aircraft, there have been numerous studies and analyses of strategies, tactics and techniques for saving fuel. Airlines no doubt perform small studies of this type every day and most of them are not published. Almost all potential actions involve some cost/benefit trade-off. Rare options which require no additional cost or other compromise are instituted as soon as possible.

While completed in 1978, before the second large fuel price rise which occurred in 1979, a study made by the Aerospace Corporation for the Department of Energy[1-10] is still a convenient reference. No list of potential fuel saving options can be complete for all airlines because of peculiarities in equipment, in procedures, or some practices which an individual airline may not have perceived as costing fuel. But, in its so-called "47 Strategies," Reference 1-10 reviews a list of optional improvements which may be considered, aside from major equipment additions to the airlines or the ATC system.

These Energy Saving Options include: Improved Airline Maintenance Procedures; Improved Airline Flight Preparation; Improved Airline Loading and Taxi Procedures, Improved Airline Flight Procedures; Improved ATC Procedures, Improved Equipment and Facilities. They are reproduced here as Figure 11-3. Lists compiled by individual airlines and others are likely to be different in detail, but should fall into the same general categories.

It should be stressed that evaluation of any fuel-saving option by one airline may be positive, while another may be negative. The result could depend not only on the airline's equipment and route structure, but on its financial situation, including interest rates. Aerospace evaluated all of the items in Figure 11-3 and discarded some which, in light of more recent price rises, now may be cost-beneficial.

That may be an important message. An option which appears unfavorable under one set of circumstances, may become favorable when conditions change. Airlines may wish to program their evaluation exercises so that they can be re-run conveniently. Or sensitivity analyses may be performed to indicate how and when different options may become feasible.

If favorable options of the 47 Strategies were implemented, it was estimated that some 6-8% improvement would be achieved with existing airline and ATC equipment, and that up to 12.5% additional saving might be attained by buying some new equipment. A rough accounting of the items and potential savings is given in Figure 11-4. These lists have since been scoured, and it is expected that airlines now have probably incorporated most of these favorable options.

For example, the Aerospace Corporation continued its pursuit of the first of the 47 Strategies: Improved Airframe Maintenance in collaboration with Continental Airlines.[11-2] "Subsequently, strategies involving the improvement of airframe maintenance, instrument maintenance, and engine maintenance to correct compressor blade erosion were chosen by the DOE as candidates for further investigation. The estimated total fuel savings obtainable from implementation of these strategies ranged from 2.3 to 3.8 percent of U.S. commercial air transport fuel consumption, or 230 to 380 million gallons of jet fuel per year. Estimated savings attributed to the individual strategies were between 0.5 and 1.5 percent for improved airframe maintenance, 0.5 and 1.0 percent for improved instrument maintenance, and about 1.3 percent for improved engine compressor maintenance. . . . commercial jet transport aircraft in normal revenue service are subject to small changes in airframe surface condition known as airframe discrepancies, resulting in small increases in aerodynamic drag and fuel consumption."

So the net percentage improvements were likely to be small but, as has been seen, their effects on airline profit-and-loss are significant.

As a first task, the continued study developed performance algorithms which were applied to the Continental Airline (CAL) fleet of DC-10-10 aircraft to indicate fuel savings which might be realized by removing a wide variety of airframe discrepancies. "Cost effectiveness was then assessed by discounting projected fuel savings to present value, and then comparing them with airframe maintenance costs." The effects of interest rates could therefore become important. As a second task, fuel savings resulting from the removal of discrepancies on two CAL aircraft were evaluated during normal revenue service. "This was accomplished by collecting pre- and post-airframe-maintenance revenue service flight data. Multivariable regression analysis techniques were then used to evaluate drag reductions and maintenance-related fuel savings."

Appendices of (1-10) detail the methods used and provide a basis for extending them to other aircraft types.

Discrepancies were classified as either surface or seal irregularities, or as misrigged control surfaces. The fuel penalty was developed by assuming that drag penalties in taxi, takeoff and descent phases are negligible. ". . . fuel penalty is incurred only in the climb and cruise flight phases. . . . Use of the procedures shows that for medium-to-long stage lengths, a 1 percent increase in aerodynamic drag will produce about a 1 percent penalty in fuel burned, a result which is consistent with physical considerations."

Based on the analytical evaluation, it was concluded that removal of aerodynamic discrepancies from the CAL fleet could produce cost-effective fuel savings of about 0.4% of the fleet fuel usage. Similar results would be expected with other airline fleets. Some post-maintenance flight evaluations of one of the two aircraft were inconclusive, believed to have been taken during unstabilized flight conditions. Otherwise, flight test results corroborated the analytical projections.

It should be noted that scatter in the test data is perhaps three to four times as great as the drag reductions being sought. Therefore statistical analysis and multiregression techniques are needed to evaluate the results.

Gallimore of Boeing,[11-3] with good reason suggests that such maintenance-improvement items should receive some tax incentive. Not only is the maintenance fairly expensive and are the results difficult to evaluate, but accomplishment of the maintenance is very well documented through the airplane logs. Addition of a tax incentive would help to offset the disadvantage of high interest rates in the cost of correcting these discrepancies.

Gallimore, Aerospace and others have noted the rather significant and consistent improvements in fuel consumption which can be gained by maintaining engine compressor and fan blades closer to their original profile shapes. Approximately 1% of engine thrust specific fuel consumption can be recovered by essentially first-approximation reforming of eroded or warped compressor blades, while another 1-to-1 1/2% can be gained with control of the fan blades. The costs of this type of maintenance will require careful assessment, since engine disassembly and reassembly costs are high.

Another appreciable, but more elusive loss occurs in engines as engine seal gaps begin to open, particularly at the tips of blades. Tests indicate that, after corrective maintenance, engines rapidly resume their deteriorated seal conditions. It may be that centrifugal, gyroscopic or other forces associated with

Figure 11-3

Energy Saving Options
47 Strategies - 1978

CATEGORY/OPTION	DESCRIPTOR
<u>IMPROVED AIRLINE MAINTENANCE PROCEDURES</u>	
IMPROVED AIRFRAME MAINTENANCE	IMPROVE AERODYNAMIC CLEANNESS
IMPROVED INSTRUMENT MAINTENANCE	IMPROVE INSTRUMENT CALIBRATION
IMPROVED ENGINE MAINTENANCE	IMPROVE ENGINE THRUST SPECIFIC FUEL CONSUMPTION
DECREASED USE OF THE APU AND ENGINES FOR MAINTENANCE	USE COMMERCIAL OR DIESEL POWER SOURCES
<u>IMPROVED AIRLINE FLIGHT PREPARATION</u>	
IMPROVED COMPUTER FLIGHT PLANNING	OPTIMIZE FLIGHT PLANNING FOR MINIMUM FUEL ROUTES AND ALTITUDES
INCREASED NUMBER OF ALTERNATIVE AIRPORTS	PROVIDE ADDITIONAL ALTERNATIVES CLOSE TO PLANNED ROUTE
AVOIDANCE OF FUEL TANKERING	REDUCE QUANTITY OF UNUSED FUEL TRANSPORTED
IMPROVED WEATHER FORECASTING	EXPEDITE FORECASTING AND ACCURACY OF ATC SYSTEM WEATHER CONDITIONS
REDUCED FUEL RESERVES (INCLUDES RECLEARANCE)	REDUCE LEGAL REQUIREMENTS FOR RESERVE FUEL
USE OF ONE-STOP FLIGHTS	REDUCE AIRCRAFT OPERATING WEIGHT OBY CARRYING LESS FUEL
USE OF ALTERNATIVE AIRCRAFT	MATCH AIRCRAFT TYPES MORE CLOSELY TO MARKET DEMAND
REDUCED NONREVENUE FLYING	RESCHEDULE AIRCRAFT TO OPTIMIZE POSITIONING
USE OF SIMULATORS FOR PILOT TRAINING	INCREASE USE OF GROUND-BASED TRAINING METHODS
IMPROVED CREW EDUCATION	TRAIN FLIGHT AND MAINTENANCE CREWS IN FUEL CONSERVATION TECHNIQUES
INCREASED SEATING DENSITY	IMPROVE UTILIZATION OF EACH AIRCRAFT

Figure 11-3

Energy Saving Options (Continued)

CATEGORY/OPTION	DESCRIPTOR
<u>IMPROVED AIRLINE LOADING AND TAXI PROCEDURES</u>	
LOADING OF AIRCRAFT FOR MAXIMUM CRUISE EFFICIENCY	LOAD TO AFT CENTER OF GRAVITY TO REDUCE CRUISE DRAG
TAXIING WITH LESS THAN ALL ENGINES RUNNING	CONSERVE GROUND TAXI/IDLE FUEL
REDUCED OPERATING EMPTY WEIGHT	MINIMIZE PASSENGER-RELATED AND OTHER ONBOARD EQUIPMENT
<u>IMPROVED AIRLINE FLIGHT PROCEDURES</u>	
OPTIMIZED TAKEOFF AND CLIMB PROCEDURES	OPTIMIZE PROCEDURES FOR MINIMUM FUEL USE
OPTIMIZED CRUISE MACH NUMBER SELECTION	OPTIMIZE CRUISE PARAMETERS FOR MINIMUM FUEL USE
OPTIMIZED ALTITUDE SELECTION	SELECT CRUISE ALTITUDE TO MINIMIZE FUEL USE
IMPROVED TRIM MONITORING AND CONTROL	REDUCE TRIM DRAG THROUGH MORE FREQUENT MANUAL ADJUSTMENT
IMPROVED ENGINE BLEED AIR MANAGMENT	REDUCE ENGINE BLEED AIR REQUIREMENTS TO INCREASE EFFICIENCY
OPTIMIZED DESCENT PROCEDURES	OPTIMIZE PROCEDURES FOR MINIMUM FUEL USE
REDUCED/DELAYED FLAP APPROACHES	UTILIZE REDUCED DRAG CONFIGURATIONS OF FINAL APPROACH
TWO-SEGMENT APPROACHES	UTILIZE LOW POWER NOISE ABATEMENT APPROACH TO CONSERVE FUEL
OVERWEIGHT LANDINGS	RE-EXAMINE FAA REGULATIONS TO RELAX GROSS WEIGHT REQUIREMENTS
<u>IMPROVED ATC PROCEDURES</u>	
FLOW CONTROL	OPTIMIZE ATC AIRCRAFT FLOW MANAGEMENT TO MINIMIZE FUEL USE
LINEAR HOLDING	SUBSTITUTE REDUCED CRUISE SPEED FOR TERMINAL AREA HOLDING
GATE HOLDING	MINIMIZE LENGTH OF DEPARTURE QUEUES

Figure 11-3

Energy Saving Options (Continued)

CATEGORY/OPTION	DESCRIPTOR
PROFILE DESCENTS	USE NONPRECISION APPROXIMATION TO OPTIMIZED DESCENT PROCEDURE
OPTIMUM HOLDING PROCEDURES AND PRIORITY	OPTIMIZE HOLDING AND PRIORITY STRATEGIES TO REDUCE FUEL CONSUMPTION
REDUCED FINAL APPROACH SPACING	INCREASE AIRSPACE CAPACITY AND THEREBY REDUCE DELAYS
INCREASED AIRSPEED LIMITS BELOW 10,000 FEET	OPTIMIZE LOW-ALTITUDE FLIGHT OPERATIONS
RELAXED NOISE ABATEMENT PROCEDURES	CONSIDER FUEL USE IMPLICATIONS OF NOISE ABATEMENT PRECEDURES
REVISED SIDS/STARS	SHORTEN APPROACH AND DEPARTURE ROUTING
AIR TRAFFIC CONTROLLER AWARENESS	TRAIN CONTROLLER IN FUEL CONSERVATION TECHNIQUES
REDUCED AIRPORT LIGHTING FACILITIES ENERGY CONSUMPTION	SCHEDULE RUNWAY LIGHTING USE ACCORDING TO TRAFFIC AND REDUCE FACILITIES ENERGY CONSUMPTION
REVIEW RESERVED AIRSPACE	REDUCE REQUIREMENTS FOR INDIRECT ROUTING
<u>IMPROVED EQUIPMENT AND FACILITIES</u>	
AREA NAVIGATION/DIRECT ROUTING	REDUCE ROUTE CIRCUITY AND IMPROVE ALTITUDE SELECTION THROUGH USE OF AREA NAVIGATION
AIRBORNE PERFORMANCE COMPUTER SYSTEMS	PROVIDE AIRBORNE COMPUTERS TO AID OPTIMUM SELECTION OF FLIGHT PARAMETERS
IMPROVED ALTIMETRY/REDUCED VERTICAL SEPARATION	INCREASE ALTITUDE ASSIGNMENT FLEXIBILITY
IMPROVED TAXI METHODS/TOWING	TOW AIRCRAFT TO CONSERVE GROUND IDLE FUEL
IMPROVED TAXI METHODS/POWERED WHEELS	USE UPGRADED APU TO PROVIDE POWER TO AIRCRAFT WHEELS FOR TAXI
INCREASED NUMBER OF ILS AIRPORTS	REDUCE GO-AROUNDS THROUGH USE OF INSTRUMENTATION
SEPARATE GENERAL AVIATION RUNWAYS	REDUCE TERMINAL DELAYS BY SEPARATING FAST AND SLOW TRAFFIC
USE OF MOBILE LOUNGES	MINIMIZE GROUND TAXIING

Figure 11-4

1978 Aerospace Study

OPTION	APPROX. % OF FUEL SAVED
NEAR TERM (EXISTING EQUIPMENT)	
IMPROVED AIRLINE MAINTENANCE	1.0-2.5
IMPROVED FLIGHT PREPARATION	0.2-0.4
IMPROVED LOADING AND TAXI PROCEDURES	0.2
IMPROVED FLIGHT PROCEDURES	1.2-2.2
IMPROVED ATC PROCEDURES	2.0-2.5
SUBTOTAL	6-8
LONGER TERM (NEW EQUIPMENT)	
AREA NAVIGATION/DIRECT ROUTING	3.5
AIRBORNE PERFORMAMCE COMPUTER SYSTEMS	3.0
OPTIMIZED DESCENT PROCEDURES	2.3
OPTIMIZED CRUISE MACH NUMBER	2.0
FLOW CONTROL	1.7
SUBTOTAL	12.5
TOTAL OF STUDY OPTIONS	18-20%

operation distort or rapidly wear down seals. Boeing has suggested that airloads from the nacelle may distort an engine into an oval shape in many flight conditions, so that only one or two flights will re-open seal losses. This area is receiving a great deal of attention.

Others of the 47 Strategies, or their variations, receive attention from time to time in the press. *Aviation Daily*, November 30, 1981, headlines, "Ground Compressed Air Systems Gaining in Popularity." The article points out that domestic airlines ". . . use 350 million gallons of fuel per year to run auxiliary power units (APUs) to generate electrical currents and compressed air to aircraft on the ground, but a switch to electric-powered compressors could yield cost savings on the order of 20-40%, according to a study by the Air Transport Association." [11.4]

The article reports on meetings of a 26-member stationary ground power/fixed air system task force, showing the results of fixed power systems in replacing customary use of aircraft APUs for servicing aircraft at the loading gate. It will be noticed that one of the 47 Strategies suggested APUs not be used to power aircraft during maintenance operations; ground-supplied power should be used instead.

"Installation of centralized ground power systems providing 400Hz power to aircraft on the ramp has risen sharply since the first system was installed in 1972, ATA said. There are now 52 central ground power systems installed or under construction at 37 airports supplying ground power to about 714 gates . . . Most of these type systems provide air for both cabin heating and cooling as well as engine starts, which would make the use of an APU unnecessary."

"Price of a 400 Hz ground power system is placed between $35,000 to $60,000 per gate. ATA said that the savings from use of such a system 'usually provides payback of the system installation in less than one year.'" ATA provided a chart comparison showing the hourly operating costs for APUs in different aircraft, as compared to a truck-mounted APU system and the central systems. Their chart is reproduced as Figure 11-5.

Not only is the visible saving impressive, two additional savings do not appear here. If the fuel used to power the aircraft's on-board APU had been carried from a previous airport, then

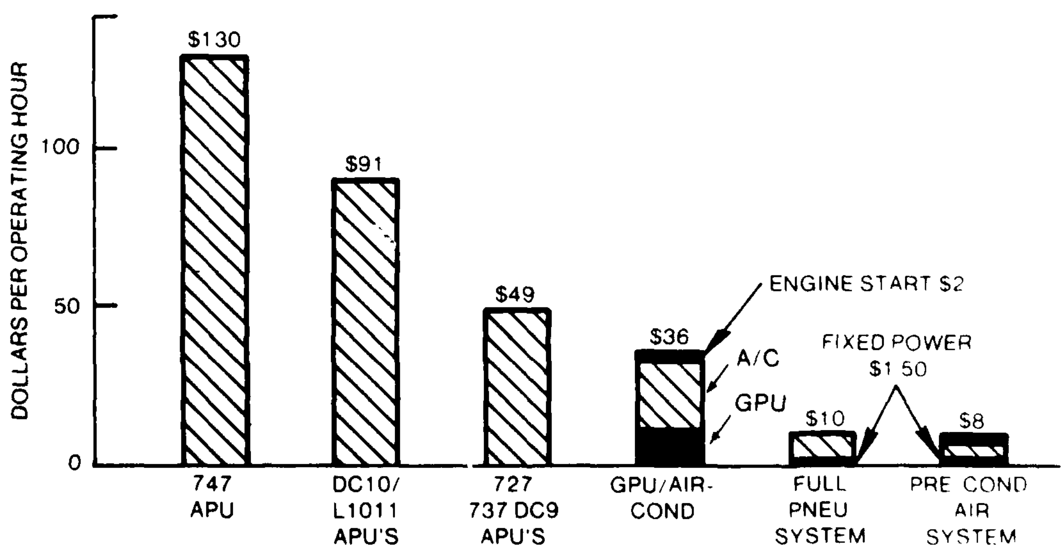

Figure 11-5

Auxiliary Power Unit Versus Ground Systems Cost Per Operating Hour

additional 20% fuel costs could be assessed for tankering the fuel to the present airport. Second, and probably the reason a system was installed in 1972 prior to the 1973 crude embargo, the central system decreases exhaust emissions at the airport ramp. Particularly today with additional gate-hold times, the incentive for central power systems has increased.

The ground power system industry has been revolutionized within the past few years, largely because of emissions and fuel conservation.

A comment may be appropriate on the prospect of using ground vehicles to tow aircraft from their loading gates to the takeoff runway and from the landing runway to their gates. This question arises frequently. Numerous studies have been made which conclude that the fuel saving is considerable. While costs of the towing vehicles and their crews become large, there is still reason to believe that net savings could be realized. But studies have shown that aircraft should be towed at 20 mph and above for economy, while existing vehicles can tow typically at only 10 mph and below. For acceleration, operating on grades and extra braking, the tow vehicles are expected to cost twice or more than existing models. One such vehicle, which might be suitable, is used to tow aircraft between distant areas at Charles de Gaul Airport in Paris. Being a single model, its cost was prohibitively high.

The number of ground vehicles required for towing aircraft becomes large and, during heavy traffic periods, there can be congestion in the ground vehicle traffic picking up loads. There is also a system problem of coordinating the two fleets, particularly in providing a pick up vehicle promptly for each landing aircraft, so as to not tie up the taxiway system. Communication problems multiply in airport areas already congested with radio frequencies, while there remain the questions of who retains control of the airplane during towing, who is responsible for safety and liability; who will buy and operate the tow vehicles? Since virtually each airport in the U.S. is a separate operating entity, coordination into a single, compatible system would require widespread support.

When the ATC system can provide tight metering and spacing of aircraft arrivals, then the ground towing concept may appear more attractive. Under present traffic and congestion conditions, neither airlines nor airport operators regard the concept favorably.

The foregoing comments have been concerned with only a few items listed in the 47 Strategies. Much additional material is in the literature.

Future Operational Conservation Potential

Gallimore and others [11-7] have reported on the need for additional relaxation or modifications in ATC procedures. E.H. Price comments that, "A one minute premature descent on every trip in 1980 would have cost Eastern Airlines over $5,000,000 in wasted fuel." [11-7] Some have observed that aircraft noise levels being lower, it is appropriate to re-evaluate noise-abatement procedures to determine their effects on fuel consumption. This re-evaluation could be justified also by rising fuel costs.[11-8] It has been noted [11-7] that replacement of the noise-related aircraft departure procedures in FAA Advisory Circular 91-39 were improved by FAA AC 91-53 enough to save over a hundred gallons of fuel per takeoff in light-weight 747s. Other comments refer to the present ATC need for 2,000-foot vertical separations above 29,000 ft., restricting aircraft to a maximum speed of 250 knots below 10,000 feet, and increased use of area navigation (direct routes) instead of airway routes (which follow VOR radio beacon sites).

In general, airborne equipment is more modern, more versatile and more fuel efficient than its corresponding ATC ground equipment. Airlines adopt equipment which permit them to fly more directly and more efficiently. The new family of aircraft procured in the 1980s will intrinsically provide better fuel economy. But, in addition, they will carry airborne performance computers which, by early service tests, are found to permit additional fuel savings of between 2.5% and 4.5%.[11-6] Current designs can also benefit with performance computers. "McDonnell Douglas and Delco Electronics have teamed to develop a computer-based performance-management system for the Douglas DC-9 Super 80 transport. A reduction of 2% in the fuel burn of the Super 80 is expected . . . ."[11-9] It is understandable why aircraft operators chafe at the limitations of existing ATC ground equipment.

Although the FAA sponsored and successfully fought international battles for world standardization on the U.S.-designed Microwave Landing System (MLS), limitations in funds have prevented relacement of the older Instrument Landing Systems (ILS) at U.S. airports. These replacements will come with time and money, relieving traffic from a single, rigid, straight, shallow approach corridor at airports. More flexibility will yield direct fuel savings but, probably more important, will improve landing rates and reduce delays.

Potential of Aviation Weather

One of the most promising possibilities from the standpoint of direct payoff, early technical feasibility, reasonable cost, and numerous peripheral benefits, is improvement of the present aviation weather system. Most of our present problem stems from the fact that we do not generally have timely, accurate current aviation weather information, while forecasts are necessarily based on the same information. As has been observed, "The ATC system of today uses the wind system of the 1940s."

Part of this problem arises from the fact that the National Weather Service (NWS) is legally responsible for all U.S. civilian weather information and forecasts. With requirements from other customers such as agriculture, shipping, storm warnings, etc., aviation can expect little special treatment. At the same time, FAA is responsible for using these weather data but, except for collecting local information at airports and other spots as delegated by the NWS, FAA must develop all its ATC strategy and tactics from NWS data and forecasts.

NWS is more concerned with surface weather than with that aloft. Observations are made twice in each twenty-four-hour period by releasing balloons and observing their tracks with theodolites. Not only are more modern methods available, but more frequent data are sorely needed. Recalling from Figure 10-1 that a 50-knot headwind costs a DC-10 more than 10% cruise fuel, there is no doubt that ignorance of winds aloft can impact our flight plans and flight fuel significantly. Considering the sophistication in some portions of our aviation system, it is astounding how we plan most of our operations with weather data six to twelve hours old. Unfortunately, it is sometimes even eighteen to twenty-four hours old.

Aircraft flying the North Atlantic are typically equipped with inertial navigation systems (INS) which, with their sensitive ability to measure drift, can determine the local wind very accurately. Due to ATC coverage in the continental U.S., domestic aircraft usually do not carry INS. From analysis of around 20,000 flight records over the North Atlantic, NASA has concluded that reliable reporting and prediction of winds aloft alone would yield a potential 3% reduction in fuel burned.[11-10]

This saving would be [illegible] from improving the wind components, not including fuel saved by reduced weather delays and re-routings.

The working levels at NASA, FAA [illegible] and NWS agree on the value of a more effective [illegible] weather program, its practicality with existing [illegible] the feasibility of frequent, accurate data and forecasts [illegible] compatibility with new subsystems being planned at NWS [illegible] as well as with the new NWS/FAA/DoD weather [illegible] program. As reported by ***Aviation Daily***, August 27, [illegible] the [illegible] commercial airline industry could realize [illegible] annual fuel savings if current weather [illegible] according to a recent NASA study [illegible] the cost of such state-of-the art [illegible] upper-air forecasts and [illegible] at $[illegible],000 per year. One-time [illegible] would be about $1 million, he said.

It is hoped [illegible] weather concept will be incorporated as [illegible] new NWS and FAA systems. It could be [illegible] the automated FAA ATC system [illegible] penalties from the existing [illegible] simply would not be tolerated if [illegible]

FAA and Other Fuel Saving Aids

For airline operators [illegible] operators or individual private pilots [illegible] considerable assistance available for those who want to conserve fuel. Many organizations have developed their own [illegible] models and algorithms. But a variety of tools [illegible] the aviation public at no cost and it is doubtful whether [illegible] potential beneficiaries are fully aware of their existence.

For example, the [illegible] and Energy's Energy Division issued [illegible] "Energy Modeling for Aviation." The [illegible] at that time included information which [illegible] B-747, B-727, DC-8, A-300 and L-1011.

VARYMOD [illegible] to fuel consumption with any maneuver [illegible] potential energy, kinetic energy, thrust or [illegible] program guides the user to enter the necessary [illegible] flight segments, and then displays the fuel [illegible] consumption rate for that segment. Although [illegible] are in fuel burned, such as nautical miles per pound of fuel, the user can select his answer from any of 22 different [illegible]. A typical example varies speeds and altitudes for a B-747. The results can be seen either in tabulated form or by automatically plotted graphs.

LINKMOD works from the same algorithms as VARYMOD, linking the individual segments [illegible] complete flight profiles, including takeoff, climb, cruise, approach, etc. Again, the computer prompts the user on the options he can select and the data he inserts at each [illegible]. For example, effects of various noise abatement procedures [illegible] variations, cruise altitude selections, or approach profiles can be selected.

Those interested further can either write the Chief, Energy Division (AEE-200), FAA, 800 Independence Avenue, S.W., Washington, D.C. 20591 or call (202) [illegible]-9717. That office will advise on model use and on later developments, as well as activity of others in this field. A technical discussion of the simulation models is given in Reference 11-13.

Additional algorithms which [illegible] into these programs are OPTIMOD, for optimum flight planning, and SIMMOD, which simulates the air traffic control system for procedures, routings and scheduling effects.

For GA operations, FAA AE-200 has also published, "Energy Conservation Potential of General Aviation Activity," in September 1979 for aircraft less than 9,000 pounds. Further and more recent information may be obtained from the same office. Those interested are also suggested to contact the General Aviation Manufacturers Association (GAMA), National Business Aircraft Association (NBAA), Aircraft Owners and Pilots Association (AOPA) or individual aircraft manufacturers. These organizations have joined in well-coordinated programs with the Department of Transportation (FAA and the Transportation System Center) and their contractor, the Mitre Corporation, NASA and their contractor, the Aerospace Corporation, and with the National Research Council/National Academy, which provides guidance to NASA.

For aircraft operators or individual pilots who would like to save more fuel, there is abundant assistance available.

Automated Air Taffic Control System

According to ***The Washington Post*** of January [illegible], 1982, "Federal Aviation Administration chief Lynn Helms, attempting to close out a years-long debate, is circulating details of a multibillion- dollar proposal to replace aging computer equipment and further automate air traffic control. The 20-year program is designed to foster safety and fuel savings while eventually cutting technical personnel by about a third." [11-14]

"Spurred by directives from Capitol Hill, the study was already well under way when the strike began on Aug. 3 . . . . equipment would allow written messages on weather, flight plans and other matters to be beamed to cockpit computer screens. At present, this communication is by garble-prone voice radio."

"After 1990, the FAA would phase in a computer service to analyze individual flight plans and select routes that were the most fuel efficient and had the fewest conflicts with other planes. Currently, planes waste fuel by flying diversions ordered by controllers who at the last minute see the potential for conflicts ahead." That is, after 1990 the ATC system would be able to use these same algorithms that individual flights can use now on their own.

As added by the ***ICAO Bulletin*** (International Civil Aviation Organisation), "The new generation computers would permit, by the early 1990s, the introduction of computer decision-making, integrated flow management, conflict-free route clearances, fuel efficient climb and descent paths, direct routings between major terminals. . . ." [11-15]

(Noting a minor example of momentum which has developed toward fuel savings, although having nothing to do with aircraft fuel economy, the ***ICAO Bulletin*** also reported, "An interesting feature of the United States' energy-saving efforts was the opening of solar-heated aerodrome control towers at two locations. The towers are expected to get 40 per cent of all heating needs from the sun.")

As S.B. Poritzky of FAA pointed out at the Georgetown CSIS forum on aviation fuels, October 1981, [1-3] air traffic management in the U.S. has been largely, ". . . restraining programs, managing the traffic by managing the demand and by interfering with what the airplane wants to so." He pointed out that all the fuel savings a 727 airplane could achieve on a 700-mile leg, including installation of a flight management system, maintaining the airplane, and flying it with optimum economy, can be more than wiped out if it encounters a six-minute traffic hold at 6,000 feet.

As a part of the planned new ATC system, its Integrated Flight Management system would begin to unlock many traditional restrictions on flight management. It would be able to tie

in directly with individual aircraft flight management systems and automatically derive the best approximation to ideal, minimum fuel operations. Poritzky estimates gains as great as 6% could be achieved with presently planned levels of automation, of which the realtime weather network would provide between 1% and 3% with presently obtainable equipment.

Since the Microwave Landing System (MLS) will only begin to enter the ATC system in October 1982 with FY 1983 funds,(11-16) it is apparent that development and procurement of new ATC concepts and components normally do not move into operation rapidly.

Aircraft Improvement Potential

Having outlined benefits gained and which remain to be achieved in aircraft operations, including aviation weather and air traffic control, we now turn to improvements offered by introducing new aircraft into the fleet.

The February 1982 issue of ***Aeronautics & Astronautics*** features a series of articles under, "Advanced Air Transports." In the lead article of the series, Maglieri and Dollyhigh(11-17) of the NASA Langley Research Center observe from NASA's Aircraft Energy Efficiency Program: "In the past 20 years the most significant improvements were made in the propulsion system. In the next 20 years the propulsion system will be as important, but will be accompanied by improvements in advanced structural materials, active controls, digital avionics, and laminar flow control."

Steiner(3-3) shows a steady improvement of engine specific fuel consumption from the late 1950s to nearly year 2000, as seen in Figure 11-6. From around 1980 to 1990, new engines can provide about 15% improvement in fuel consumption, with about the same additional potential from 1990 to 2000. This assessment is in good agreement with others, such as Lockheed projected in an advanced technology briefing in June 1981.(11-18) Lockheed showed that an existing airplane could be improved 17% by installing a second-generation turbofan engine, while up to 11% additional could be achieved in 1990 with an advanced turbofan. See Figure 11-7.

As compared to the smaller improvements seen earlier for maintenance, flight planning, and air traffic control, it is apparent why airlines seek to buy new engines. Perhaps surprisingly, as Maglieri and Dollyhigh observe, similar large fuel savings now are obtainable from a variety of improvements in airframes.

An aggragate of the potential improvements, their time spans and relative merit were given by Steiner(3-3) and is shown here as Figure 11-8. His chart is identical to F-9 of Maglieri and Dollyhigh,(11-7) except that they show a combined potential (the upper shaded section) 10% higher than Steiner. The reason evidently is because, although he indicates a potential for laminar flow control, Steiner does not credit it in his summation. The NASA authors credit it with about half of the potential which might be attained.

Those familiar with laminar-flow control (LFC) history will be amused, and probably skeptical that it still appears in aircraft improvement plans. The concept goes back before WW-I and was actively pursued prior to WW-II. After WW-II, Dr. Otto Pfenninger was brought over from Germany to Northrop's Aircraft Division, where he conducted a considerable program under USAF/NASA sponsorship. The program culminated with flight tests of the X-21, an airplane specifically designed and built for LFC.

It was concluded that LFC does offer its predicted advantages, but that practical problems such as structural design and tolerances, control of airflow rates, and external disturbances such as bugs and dust on the surface, even acoustic noise, present significant and constant problems. Maximum LFC benefit must be achieved with rather special aircraft, having larger wing areas and smaller engines than normal; they would be more effective at the longer ranges. So the concept of sucking or blowing the boundary layer still appears difficult, but tantalizingly valid.

Perhaps encouraged by success with supercritical wings, there is a guarded feeling in industry that some LFC drag reduction may be obtained over forward portions of wings, using more careful design and construction. Composite structures could offer the contour control and rigidity that may be required.

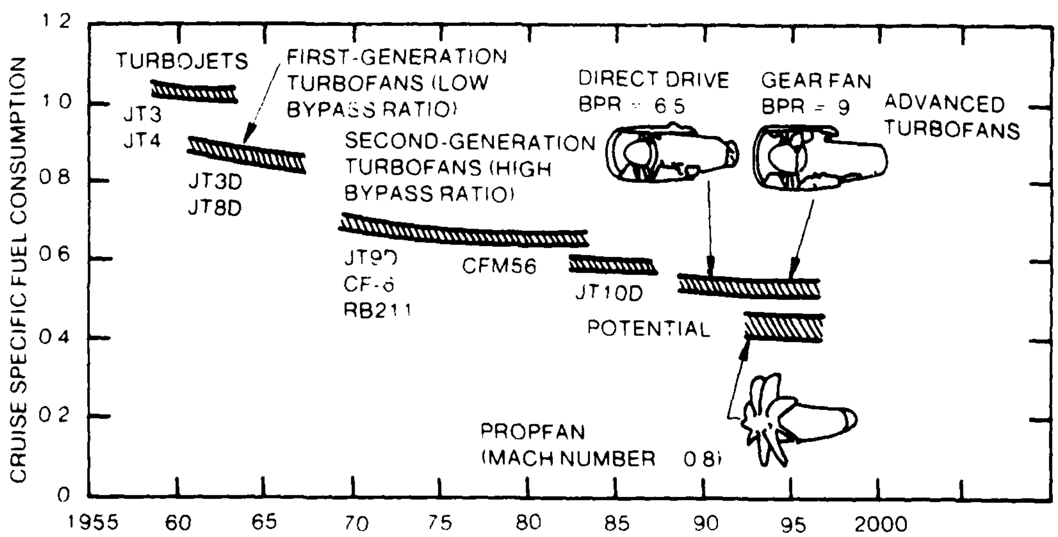

Figure 11-6

Fuel Consumption Improvements Far-Term

Figure 11-7
Lockheed Projected Technology

TECHNOLOGY	1986 F-29	1986 ATX-135	1990 ATX-135 TURBOFAN	1990 ATX-135 PROP-FAN
	% FUEL SAVINGS*			
LOW DRAG AIRFOIL	3	3	5	5
HIGH ASPECT RATIO	5	5	5	5
GUST LOAD ALLEVIATION	—	1	1	1
RELAXED STATIC STABILITY & C.G. MANAGEMENT	—	3	3	3
FLIGHT MANAGEMENT	1	1	1	1
RECIRCULATING ECS	2	2	—	—
ELECTRIC SECONDARY POWER	—	—	3	3
ADVANCED ALUMINUM	—	1/2	—	—
COMPOSITE SECONDARY	1	1/2	1	1
COMPOSITE PRIMARY	—	1	5	5
	12	16	22	22
SECOND GENERATION TURBOFAN	17	24	—	—
ADVANCED TURBOFAN	—	—	28	—
ADVANCED PROPFAN	—	—	—	38
TOTAL	27%	36%	44%	52%

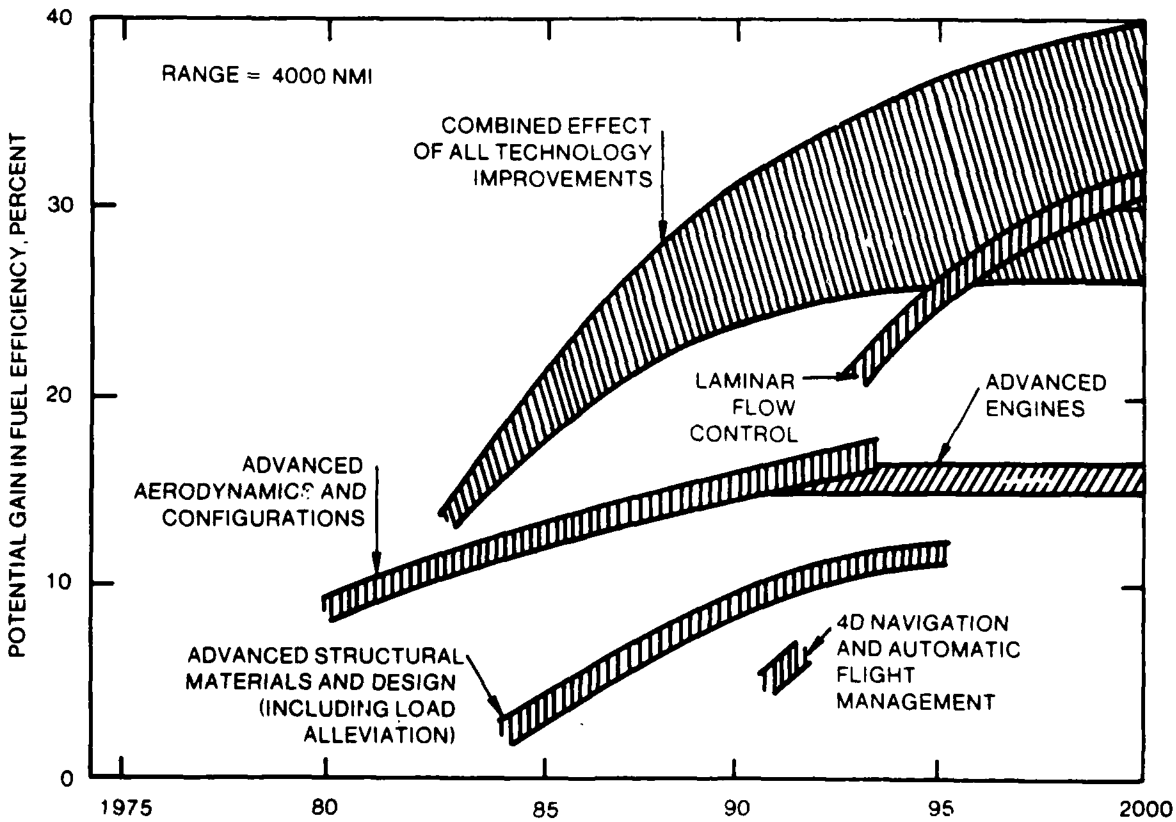

Figure 11-8
Technology Improvement

Some cryogenic cooling is also considered to stabilize the boundary layer, a concept which needs evaluation. At any rate, while designers are not racing ahead on LFC, they generally believe there may be some future potential, without the need for a powered system.

Integrated Aircraft Design

Achieving these incremental fuel savings poses some difficulties in definition and arithmetic. Increments do not necessarily add up algebraically. The process is illustrated well in a Lockheed document.[11-19]

Figure 11-9 lists the major categories of technological aircraft design elements and the candidate improvements under each. Others may be added as identified. A synthesis program for integrating these candidate improvements is outlined by Figure 11-10, which Lockheed calls "Asset." Candidate concepts are introduced to the computer model and their mutual interactions are derived to define an airplane, its characteristics, performance, cost and noise characteristics. Limits can be established for any of the outputs (such as noise) to assure all aircraft designed by the program will be comparable on the basis selected.

Notice under the cost output "box" (on the bottom level of the flow chart), that results are given for direct operating costs (DOC), indirect operating costs (IOC), return on investment (ROI) and for total system cost. So the program permits an investigator to add in whatever improvements he wishes, to the degree desired, at the appropriate times, and under defined and controlled conditions. He may investigate a variety of options to suit different conditions or forecasts.

Results may be plotted on a chart such as Figure 11-11, which shows the fuel savings achieved with each improvement, adding together with previous improvements. In effect, each of the horizontal plateaus represents a completely new airplane, synthesized and optimized for that particular set of conditions. About a dozen improvements are shown. If all are included, the total improvement would be shown by the top of the "S-CURVE" and about eight years' development lead time is needed for this airplane to enter the fleet. It is probable then, that the full potential could not have been completely accountable at the time the first improvement was available. Competition demands forecasting of some yet unachieved improvement. And technical accumulation time is required for each new aircraft generation.

The results of one particular analysis made by this method is tabulated in Figure 11-7 and shown in the bar comparisons of Figure 11-12. In terms of available seat-miles per gallon (ASM), Fig. 11-12 includes a typical low-bypass ratio family aircraft (DC-9 or B737) for comparison. It produces just under 50 ASM/gallon. By going to a 1986 version of the Fokker F-29, improving the wing, and slightly the flight management system,

Figure 11-9

Potential Technological Elements

STRUCTURES, MATERIALS AND MANUFACTURING PROGRAM	AVIONICS, CONTROLS AND SYSTEMS DEVELOPMENT	PROPULSION SYSTEM PROGRAM	INTEGRATED WING DESIGN PROGRAM
COMPOSITES	IMPROVED FLIGHT STATION DISPLAYS	ENERGY EFFICIENT TURBOFAN	AIRFOIL TECHNOLOGY
ADVANCED ALUMINUM ALLOYS	ACTIVE CONTROLS	PROPFAN	HIGH LIFT TECHNOLOGY
TITANIUM FORMING AND BONDING	DIGITAL AVIONICS	AIRFRAME/PROPULSION INTEGRATION	C.G. MANAGEMENT
HIGH STRENGTH STEELS	DIGITAL FLIGHT CONTROLS	INLET DESIGN TECHNOLOGY	ADVANCED AIRFOILS FOR PROPFANS
ADHESIVE BONDING	FLY-BY-WIRE	ALTERNATE FUELS	ACTIVE CONTROLS
HYBRID STRUCTURE	FLIGHT CONTROLS ANALYSIS AND SYNTHESIS		ADVANCED FLIGHT CONTROLS
INDUSTRIAL ROBOTS	SOFTWARE MONITORING AND MANAGEMENT		AIRFRAME/PROPULSION INTEGRATION
	ELECTROMECHANICAL ACTUATORS		ADVANCED MATERIAL
	ADVANCED SECONDARY POWER SYSTEM		
	FIBER OPTICS		
	4-D NAVIGATION - TCV		
	FLIGHT MANAGEMENT		
	IMPROVED BRAKES		

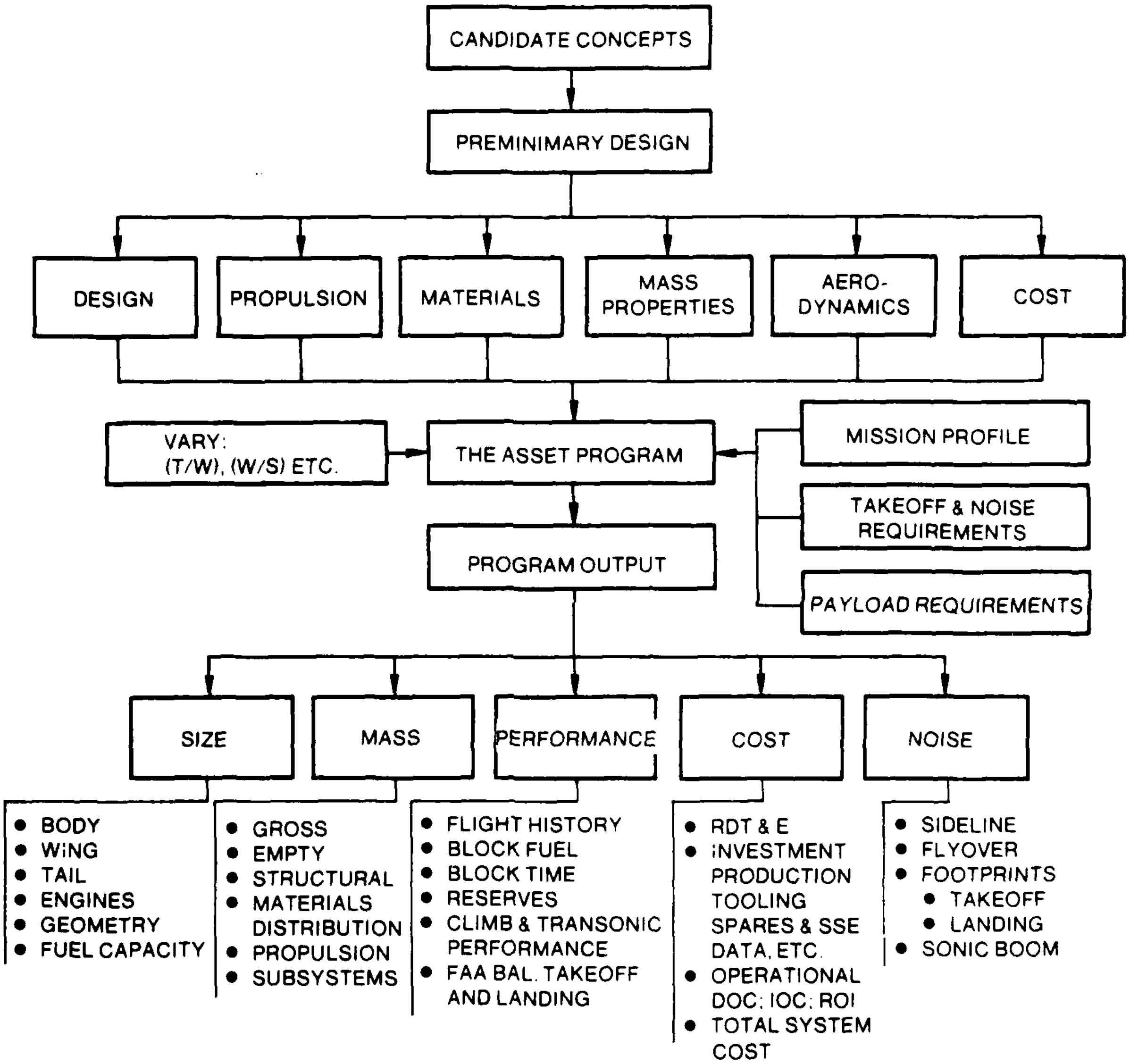

Figure 11-10
Vehicle Synthesis Program

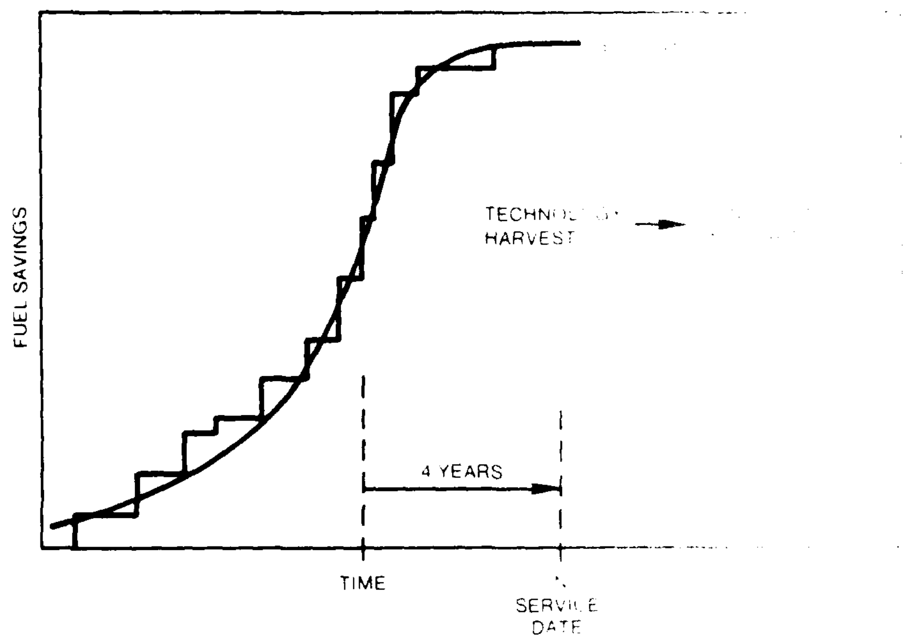

Figure 11-11

environmental control system and some composite secondary structure, the airplane would achieve a 12% improvement in fuel consumption. Replacement of current engine designs with a second-generation turbofan would achieve another 17% saving, for a net of 27% available in 1986. (Notice that, although the aircraft increments add to 12%, the new airframe and engine improvements do not add directly; this is one result of the synthesis process.)

Figure 11-12 shows the potential customer, Delta Air Lines, a 27% improvement which could be achieved by modifying an existing design in 1986. This is compared with what could be achieved with a completely new design, providing a net 36% improvement, which could have been produced by 1986. By comparison, Delta was interested in achieving over 40% by 1986, about 84 ASM/gallon. Lockheed showed they could slightly exceed that goal, but not until about 1990. Lockheed also showed that a 1990 propfan design would be able to show a 52% saving.

This propfan powerplant is generally illustrated by the lower righthand figure in Figure 11-6, a multiblade, thin, swept-blade fan. The propeller has not been fully developed, nor has its gearbox. Development would require very active support by NASA.

In various design studies, competitive turboprop aircraft designs have been cruised at speeds directly comparable with their jet counterparts. It may be debatable whether high cruising speed is really economical at these short ranges. The rapid acceleration and climbout, and perhaps a lower altitude for best cruise inherently provided by a prop, might achieve the same schedule time with a lower cruise speed. It may also be questionable whether the props and gearboxes will be quiet, or whether passengers will simply dislike propeller-powered aircraft.

Future Fuel Economy

It should be recognized that the "S-CURVE" limit of Figure 11-11 is transitory. As new improvements are developed and become [illegible] improvements are necessarily speculative [illegible] designers in both the engine and airframe [illegible] that further improvements [illegible] aircraft are likely to continue [illegible] see a 50% improvement from [illegible] 50% of the remainder from 1990 [illegible] far ahead for anyone to guess [illegible] improvements in fuel [illegible]

Future fuel economy [illegible] does not appear to be limited [illegible] probably a matter of airline [illegible] and other operators want [illegible]

As Magnet [illegible] increasing price of fuel, the [illegible] savings can offset substantial [illegible] attaining profit margins [illegible] of new technology [illegible] a rising fuel price [illegible] and may accentuate other [illegible] may provide less [illegible] they, too, may become [illegible] life.

The [illegible] aircraft will probably be determined [illegible] finance them, rather than [illegible] Therefore, improved [illegible] costs must be considered [illegible] aircraft mixed in with [illegible] investments also must pay off [illegible] enthusiasm toward higher priced aircraft [illegible]

The new technology [illegible] variety of fuel improvement options [illegible] costs and times. If each airline [illegible] should be relatively simple [illegible] technology and costs to fit those needs [illegible] procedures provide reliable methods [illegible]

Financing may [illegible] step in the whole process.

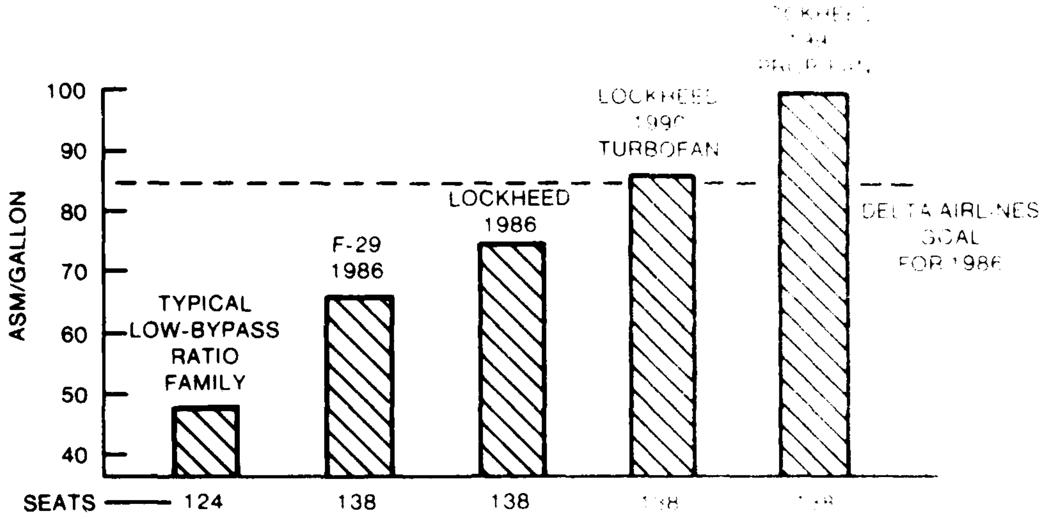

Figure 11-12
Relative Fuel Efficiency
100% Load Factor, 500 N.Mi. Trip

The Aeronautics and Astronautics Issue of February 1982

In its February issue of *A/A*, the American Institute of Aeronautics and Astronautics reports a valuable assessment of advanced transport aircraft assembled by its Air Transportation Systems Technical Committee under Chairman Saul Sokolsky of the Aerospace Corp. As outlined above, Maglieri and Dollyhigh of NASA's Langley Laboratory provided the provocative lead paper[11-17] outlining an outlook for all technical development areas.

"Thirteen industry leaders from the U.S. and Europe comment on Maglieri and Dollyhigh's portrayal of technological opportunities," is the introduction of a very brief summary article by John M. Leavens, Jr. of Douglas. The critics who participated are:

Robert T. Jones, Senior Research Scientist, NASA Ames Research Center.

Roger D. Schaufele, VP-Engineering, Douglas Aircraft.

John E. Steiner, VP-Corporate Product Development, Boeing.

Roger Berteille, Exec. VP and General Manager, Airbus Industrie.

Gordon A. Titcomb, Exec. VP, Commercial Products Div., Pratt & Whitney Aircraft.

John Coplin, Director of Technology, Rolls-Royce.

Brian H. Rowe, Senior VP and Group Executive, GE Aircraft Engine Group.

Donald J. Lloyd-Jones, Senior VP-Operations, American Airlines.

William B. Durlin, VP-Engineering and Quality Control, Frontier Airlines.

Walter J. Overend, Manager, Programs and Performance, Delta Airlines.

Rolf Stuessel, VP-Engineering, Lufthansa German Airlines.

Edmund S. Greenslet, VP-Securities Research Div., Merrill Lynch, Pierce, Fenner & Smith.

William F. Pank, VP-Aerospace Div., Chase Manhattan Bank.

Outlook [illegible] Leavens

In his short summary, [illegible] that the responses were varied but with some [illegible] agreements. "They pretty much agree about technologies likely to be available by 2000 and the magnitude of their benefits. They agree much less about what technologies will become a part of future aircraft, because the rules of the technology application game are changing."

"The desire to improve fuel efficiency currently drives technology development. [illegible] the greatest and earliest potentials are expected from propulsion, aerodynamics and configurations, structural design and materials, active controls, digital avionics, and laminar flow control in aircraft, together with air traffic control improvements on the ground.

"The reviewers [illegible] see as the greatest need a replacement for the older narrow-body subsonic aircraft, particularly on flights of less than 1000 n.mi., which account for more than half the jet-fuel consumption. These aircraft will benefit the ***least***, however, from advanced technology. This is causing the airlines to be wary of investing in advanced technology. NASA and the manufacturers want demonstrations to prove the economic risks are acceptable, while airlines and financiers call for better reliability and maintainability, deferring new technology until it is economical.

"[illegible] improvements of total fleet economics by the addition of new aircraft alone will be slow, and consequently advances will also have to be applied to aircraft still in service. [illegible] Cost savings in design, manufacture, and maintenance are as important as those from advanced technology."

Highlights from comments by the critics follow.

Jones, NASA — Since current fan-jet aircraft easily get 60 seat-miles per gallon, additional fuel economy is difficult. "Advances in propulsion have played a major part in the success of the modern transport. Where engines and propellers formerly required [illegible] of the aircraft weight, propulsion's share is now [illegible]."

The search for better fuel economy may cause future transports to fly at higher altitudes [illegible] business

jets With larger engines and high-aspect-ratio wings, takeoff and climb performance would be dramatic.

Supersonic flight necessarily consumes more fuel. Jones is skeptical of the optimism toward an SST in the lead paper. He points out the possibility of transonic flight up to about Mach 1.15, but still with some fuel penalty.

Schaufele, Douglas — 1990 technology will be extended from today's, with significant improvements in aerodynamic design (supercritical wings, interference drag, active controls). Further improvements in materials, internal systems and controls are mentioned. The multiblade propfan offers 10-15% fuel economy over comparable turbofans, but needs development by NASA.

He points out the difficulties with LFC, but notes fuel saving potential up to 20% in the late 1990s; much NASA development would be required. He agrees generally with NASA Langley's favorable view toward SST, pointing out advantages of newer aerodynamics, titanium structure and variable-cycle engines. Again, NASA support is vital.

Steiner, Boeing — He purposely addresses ***economic*** implications of the new technology. The major force advancing civil aviation has been the reduction in travel costs. New aeronautical improvements are accompanied by investment risks and may not translate readily into further expansion. Acceptance may come rather slowly.

"The U.S. does not appear to have adequate government-industry coordination and funded programs that accelerate progress through this phase. Yet much of the non-adversarial programs gaining momentum abroad aim at this phase. Thus, technology's existence will not necessarily imply U.S. application." Either the propfan or a geared high-bypass-ratio shrouded turbofan will require "readiness-attainment" development.

He mentions the large proportion of aviation fuel burned on short-range flights and the need to tailor aircraft more closely to those requirements. He laments the present lapse of interest in STOL (short takeoff and landing) aircraft, believing that the penalty in cruise performance is small. He expects an SST to emerge only when, "... its technology will allow substantial reductions in air fare, and in this area, it will have to compete with the efficiency improvements introduced into the large subsonic aircraft."

Noise curfews, bilateral agreements, labor contracts and oil disruptions become part of the risk assessment.

"... I believe that an improved and sustained ***oversight of national aviation policy and technology*** could do much to ameliorate or inhibit the development of the causitive factors that catch aviation with efficiency shortfalls or, for that matter, technological shortfalls that would ultimately constrain civil-aviation growth. ... It is time that we aggressively institute an oversight, at the national level, of these (economic) factors and their implications for aviation's technological responsiveness."

Berteille, Airbus Industrie — Airbus Industrie is committed to continuous development of a subsonic transport family with improving efficiency and economic profitability. He regards the computer as the means to synthesize and optimize these possibilities, including tailoring aircraft sizes to their route structures. Economic software algorithms will be woven deeper into the aircraft design process.

Risk evaluation is necessary for success, reducing project delays and costs. Progress must be by evolution rather than revolution. Testing and proving takes time, which must be scheduled carefully.

SSTs do not appear economically competitive. Propulsion improvements are "extremely important." Airbus values the NASA ACEE (Aircraft Energy Efficiency) program.

ATC systems have not kept pace with air traffic growth or with aircraft performance potential. Improvements in ATC would permit better optimization of aircraft design, in sizing, for example.

Titcomb, Pratt & Whitney — Emphasis on reduced fuel consumption is not new to engine manufacturers. The emphasis for earlier application has increased. In the '80s, fuel consumption will be reduced by better component efficiency and modest increases in pressure ratio, bypass ratio, turbine temperatures, weight reductions, and electronic engine controls.

In the 1990s, pressure ratios will increase from 30:1 to the 40s, with accompanying temperature increases. Further use of composite materials will continue to reduce engine weight.

The prop-fan appears feasible, offering 15-20% fuel savings, shorter takeoffs and lower noise. It is the only really new look in propulsion but has significant development challenges.

The next major improvement in turbine airfoils may be ceramic coatings, allowing temperature increases of more than 150°F and better fuel efficiency. Improved aerodynamic and structural integration of the propulsion system into the airframe may offer additional fuel economy.

Coplin, Rolls-Royce — "Although fuel cost is plainly the most important factor, manufacturing cost and its influence on price is far more important than simple exchange rates would have us believe, mainly because of competition. We are in a rising business and others outside the established industry want to take a share of the business and this will increase competition, which is already very severe — many would say too severe."

"We must tackle the challenge of introducing new technology at low cost through a combination of low labor costs, automation, and well conceived advanced-technology management in engineering and manufacturing."

He points out the interaction in technologies and how a small advance in one area may unlock a series of greater advances in other areas. But the emphasis must be to improve efficiency at low cost, no cost, or reduced cost.

He believes an SST will justify itself around the turn of the century. Aerospace technologies may offer opportunities in areas outside aviation. For example, ceramic developments may make the adiabatic diesel engine possible for automobiles. In turn, such an engine may have an impact in short-range aviation.

Rowe, GE — "Continued growth of the air-transport industry requires productivity improvements, not only for improved economics, but also to avoid congestion problems of airports." Emphasis will still be on fuel consumption, lower first costs (because of debt-to-equity ratios) and lower weight. But because of airport traffic limits, emphasis will be on larger sizes.

Larger engines pose no unique problems, except for greater emphasis on weight and materials. Increased temperatures with better materials will decrease fuel consumption and engine size.

Renewed interest in turboprops should be expected for their fuel efficiency. There will be tremendous emphasis on automation toward reducing manufacturing costs and, "doing it right the first time."

Without dramatic break-throughs in drag, structures and engine noise, an economic SST cannot be foreseen.

Lloyd-Jones, American — "The air-transportation industry has undoubtedly undergone the most extensive transformation during the 1970s compared with any similar time span in the industry's history. ... These problems have been forcing a large number of air-transport aircraft into a state of economic and technical obsolescence. Fuel conservation and fuel effi-

ciency have taken on a new meaning and urgency. It is imperative that the air-transportation industry bring on line the new fuel-efficient aircraft so badly needed to improve the profit picture; yet, the depressed profit situation is making it difficult to finance the needed equipment."

The NASA aeronautical program has represented only about 10% of its budget, but the ACEE project has been valuable. Budget restrictions now require strong selectivity in R&D. Many of the new programs, such as the prop-fan, composite structures, and the energy-efficient engine, will not be ready for the 150-seat, twin-engined transport. Probably we should at least postpone long-term prospects such as LFC, concentrating more on the near term. New technology should not introduce economic surprises. Reliability is essential.

Particularly with new technology, we must balance, ". . . safety against overly burdensome certification requirements."

Unless the ATC system keeps pace, it could, ". . . become the major restriction to industry growth and negate much of the gains achieved from the fuel-conservation technology."

Durlin, Frontier — "Increasingly larger capital investments will have to be protected by greater productivity and efficiency built into the transport aircraft. . . . With the next generation, medium-sized transport aircraft used in the short-to-medium range markets, however, increased productivity by virtue of size increase will no longer be possible because of market capacity. . . . lower operating and maintenance costs together with better utilization and reliability must build productivity."

Some components of aircraft systems have not improved or kept pace with technology in reliability and maintainability. Gaining access to a critical area may take more time than making the repair. "Failures in mechanical and flight-control systems often lead to complex step-by-step rigging procedures with numerous (but necessary by design) checks requiring hours and sometimes days of downtime." More built-in testing should be possible.

Aircraft mechanical systems require far more servicing than comparable or more complex automobile systems. Candidates for improvement include wing-flap drives, airstair actuators, and door-operating mechanisms. "Aircraft must be able to operate with system faults; repairs or replacements should be possible without service disruption."

Since increased productivity cannot be obtained through increased speed or size, the increased capital costs must be offset by better utilization, reliability and maintenance.

Overend, Delta — In the tight squeeze between fares and costs, advanced technology may be financially risky and its value must be well known. R&D has not been able to simulate service life and some components fail in only 50-100 hours of operation. "Basically, design does not meet the standards essential to good economics."

Are marketing goals compatible with operating realities? Will the new structures be serviceable? Can we afford the checkout equipment and the downtimes they require? Along with technical performance, the designer must recognize the financial, legal, regulatory and other institutional demands on his design.

"Advanced technology in effect asks a higher order of knowledge in each of the phases of certification, operation, maintenance and support. As of now, it is not clear that the total aviation enterprise is prepared and willing to spend the time, effort, and cost to achieve this higher order."

Stuessel, Lufthansa — "The airlines finished 1980 with the worst financial result ever. Not only that, 1981 will probably not prove to have been better. The main reason for the present unfavorable situation is without doubt the increase in fuel costs. . . . To overcome soaring fuel prices, the fight for better fuel efficiency has become the main objective of both the manufacturers and the airlines."

Aircraft manufacturers used to aim on lifespan and productivity through evolution; now they aim at fuel efficiency. We have a clear picture of these improvements. Advanced turbofans offer a 10-15% saving; a propfan could achieve additional improvements. The supercritical wing offers a thicker wing and therefore lighter weight and greater aspect ratio. Composite structures reduce weight. Automated controls reduce fuel use up to 10% and provide a smoother ride.

"There are still serious deficiencies in optimizing traffic flow. In Europe alone, additional fuel consumption due to traffic delays causes losses of $100-120-million a year. Furthermore, the average airway distance between two cities is increased by 15% due to airspace restrictions, this being equivalent to about $300-million for the additional fuel consumed. If development on this sector of air transportation were to proceed at the same pace as that of flight equipment, substantial savings would be possible."

"One may therefore be quite optimistic for the future, concerning potential savings in fuel, with the introduction of new technologies in the fields of propulsion, aerodynamics, structures, avionics, and ATC organization. The airplane of the year 2000 should offer fuel consumption per ton-kilometer only half that of the 1980s."

"One major problem remains: providing capital for new investment at a time of stagnating traffic growth and excessively high cost of equipment." The time for return on investment has decreased, down to 3-4 years. It is doubtful the 150-seat transport should be developed now; it should wait for an improved engine in the desired thrust class.

The industry will not only have difficult financing problems, but day-to-day cash flow problems.

Greenslet, Merrill Lynch — In the past, aircraft performance or service improvements virtually assured their economic feasibility. Today, new aircraft offer no added appeal to the passenger; economic success must be assured before purchase. Other costs can be reduced and new airlines are able to use better labor productivity and total trip costs to compete with less-advanced equipment. What new technology do we need and how much should airlines pay?

The designer no longer leads the way; he must adapt to the needs of airlines which are forming the economic solutions for public demands. Heed the papers by Durlin and Overend because they represent successful airlines. Emphasis should be on performance, reliability and maintenance. The traditional market, led by companies such as PanAm, may have shifted.

Design for best fuel efficiency may become a dangerous one-dimensional trend, as speed was in the past. Due to divergent views of what is needed in a new design, the designer should take care not to choose a consensus, which may sacrifice some of the better features. "The result may be a deferral of innovative technological advances, but it should assure that when those advances do come, they will come in packages that can both be marketed by the manufacturer and financed by the airlines."

Pank, Chase Manhattan — "It has been suggested that the introduction of new technology aircraft in the post-1990 period could make possible an airline system capable of carrying three times current traffic levels with fuel consumption only 20% higher than it is today. This certainly makes one sit up and take notice."

"If, as implied above, traffic, revenue, and cash operating expense, other than that for fuel, were to triple while fuel

expense increased only 20%, cash operating profit would grow to 18.3 billion, a cash operating margin of 23%, the same as in 1966 — certainly by recent standards a very good year for the industry. The year 1966 was significant in another regard; it saw initial orders for wide-body equipment, which produced the last major increases in aircraft productivity."

"The performance of the airline industry today stands in marked contrast to what prefaced the introduction of the wide-body transports. . . . make clear the financial challenges facing the industry and ***call into question the ability of the capital markets to fully provide the support needed in the future***." Assuming historic financing ratios, the airlines estimate they will need four times the external financing of the past decade. This appears dubious, primarily because of fundamental changes in the life insurance industry.

Other industries, including energy, will be making demands on the capital markets.

One can become too caught up in current levels of profitability and leverage; one must have faith that some stresses will sort themselves out. A lender's concerns will remain basically the same: ". . . addressing the airline as a going concern and secondly in terms of liquidation." That is, considering first the effects of new aircraft on the airline's profitability and secondly, the collateral value of the equipment. "The two are very much related, for an aircraft unable to deliver adequate profit will not hold adequate value."

New technology will have to deliver its benefits with greater assurance beforehand, and with greater reliability. Airlines will need quick paybacks. There will be more emphasis on collateral value, including ability to operate profitably in off-design conditions. So many design varieties are being proposed that it is doubtful funding can be found for all of them. There are more questions in the capital market over the next 10-15 years than in succeeding years. This may provide time to make the selections and provide the validations which will be needed.

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Chapter 12

Disruption of U.S. Crude Oil Imports

Board Room Briefing No. 12

1. The U.S. has impressively decreased its importation and dependence on foreign crude oil. Only about one-third of our total petroleum crude and products are now imported. From the peak of 8.6 million BPD in 1977, to an average of 5.3 million BPD for 1981, by early March, 1982, U.S. crude oil imports dropped to 3.8 million BPD (including 0.6 million BPD for the SPR), a total drop of 56%.

2. Less than 60% of U.S. petroleum imports are now from OPEC countries, or less than 2.5 million BPD. About 55% of our OPEC petroleum, or less than 1.5 million BPD is from Arab members of OPEC, excluding Venezuela, Indonesia, Nigeria and Liberia. Of the OPEC crude, by far the largest segment comes from Saudi Arabia.

3. Another total Arab embargo of the U.S. would therefore involve less than 1.5 million BPD. In addition to OPEC, the U.S. imports substantial oil from Canada, Mexico and the Netherlands Antilles. OPEC production has dropped from 69% of free-world production in 1973 to 55% in 1982.[12-1] Cutoff of any single component of our crude oil imports will have far less impact than only one or two years ago.

4. Still, a 1.5 MMBPD Arab cutoff would disrupt U.S. commerce seriously, while a sustained cutoff of as much as the total 3.8 MMBPD would be devastating. It is difficult to construct a scenario now under which the entire 3.8 MMBPD would be halted.

5. Practically, then, it appears the U.S. should now be concerned primarily with a potential cutoff of over a million BPD from Saudi Arabia, a less likely 1.5 MMBPD cutoff by all OPEC, and as much as 3 MMBPD only in case of major hostilities or total cessation of Mideast production or shipments.

6. The 1980 National Petroleum Council (NPC) report to DOE[1-8] concluded that crude import losses up to 2 MMBPD for six months could be met by fairly moderate measures. Losses above 3 MMBPD for twelve months would require imposition of taxes and fees, drawdown of the Strategic Petroleum Reserve (SPR) and private stocks, and probably gasoline rationing.

7. In all the scenarios considered, the NPC recommended that no price controls be applied. The free market should govern prices; government intervention or allocation should be used only to protect security, health, safety, and our foreign interests.

8. The Administration has proposed an emergency energy policy which has not yet been debated in Congress. The Administration is reluctant to establish any contingency plan, which they feel could only add restrictions to an otherwise "free market." On March 20, 1982 President Reagan vetoed the Standby Petroleum Allocation Act. With worldwide oil stocks estimated now from 300 MMB to 700 MMB,[12-2] with the SPR finally making steady progress, and with other business pressing Congress, it is questionable whether an emergency program will be defined. Participants in the energy market should assume that present "free market" conditions will prevail and extend. Government intervention may occur only after a crude import disruption has occurred and has become serious.

9. The U.S. oil refining system is essentially a continuous, "flow-through" operation. Reserves are generally used only to level variations in flow. Reserves are expensive because of storage space and, particularly with high interest rates, they are an unproductive investment. Nevertheless, in three years after the Arab embargo, U.S. industry added about 300 MMB of storage capacity.[12-3] U.S. private reserves are therefore somewhat greater than the SPR at present.

10. In April 1980 the SPR stood at only 92 MMB. In April 1982, it held about 250 MMB. Until April 1981, the SPR was being filled at around 100,000 BPD, about 1/3 of its fill rate limit. Since that time, it has been filled at near the 300,000 BPD limit rate. Around the end of 1982, this rate will be reduced by necessity for additional storage capacity, so that allowable fill rate will drop to below 200,000 BPD until 1985. At that point, it is scheduled to resume at 300,000 BPD until full storage of 750 MMB is reached in 1989 or 1990.

11. It is proposed, specifically by NPC[1-8] as well as others, that 200 MMB of the SPR be held in reserve through all the crude oil disruption scenarios which have been considered. This hard-core reserve would be retained for completely unforseen emergencies and, presumably, active warfare. Since the SPR has only recently passed the 200 million barrel level, the SPR does not become an effective part of our crude-oil-disruption mechanism until about 1985. Its psychological effect, both domestic and international, may be significant during the meantime.

12. The NPC emergency preparedness study considered energy consumption in detail and a variety of significant possibilities to cope with crude oil disruption scenarios. Aviation was evaluated in the study, and was generally considered a minor demand component, although recognized as a major concern in national commerce.

13. The NPC noted that aviation has already pursued fuel conservation vigorously and effectively. They expect aviation's conservation efforts will continue with further success (Chapter 11 strongly supports their conclusion). Consequently, NPC specifically recommends no regulation of aviation until crude cutoff reaches approximately the level of 3 MMBD for twelve months expected duration. At around that 3 MMBD point, NPC

recommends that airline load factors be increased to 70-75% by increasing seating density and by combining and canceling duplicate flights. NPC also noted that aviation is essentially self-regulating, in that it cuts back service when industrial activity slows down.

NPC recognizes General Aviation as an important component of the national economy, notes that it is a relatively small user of energy, and proposes no regulation of GA under any of the disruption scenarios.

It should be noted that NPC's action merely offers recommendations to the Administration through DOE. The Administration has not responded, while Congress has not debated the subject of an emergency energy plan.

14. Barring some unexpected drastic turn in national direction, such as strong congressional opposition to loose controls in the Administrations' emergency energy plan, aviation should expect no governmental intervention in aviation affairs or fuel allocations, short of a major disruption in foreign crude oil shipments. Disruptions of less than 3 MMBD for less than six months are not likely to induce action.

15. The NPC concluded that U.S. refinery flexibility is adequate to produce the required national product slate for all disruption scenarios considered, including the most drastic. No changes in product specifications were assumed in reaching this conclusion. The NPC recommended, however, that relaxed emergency specifications should be established for distillate fuel oil and jet fuel, to relieve the demands on crude oil and refineries during major disruptions.

16. If demand for mogas continues to drop or if mogas is rationed during a major disruption, releasing more refinery light fractions, U.S. jet aircraft could operate on lighter fuels such as Jet B, for which they are already certificated. Canadian airlines have operated for more than thirty years on Jet B ("wide-cut" fuel) with a commendable safety record. [12-4]

17. Political and military analysts believe that significant disruptions in foreign crude oil supply to the U.S. are not only likely, they are probable. While these views cannot be quantified, the consensus is that up to three disruptions should be expected in any ten-year period. A few of our most prestigious analysts believe these disruptions will trigger fuel price rises comparable to those in 1973-74 and 1979-80. This author and others disagree, believing the effect on prices will be moderate. A complete cessation of Mideast oil deliveries would trigger a substantial price rise, but is believed by this author as highly improbable. Apparently that is where the difference of opinion lies: some believe a complete interruption of Mideast oil is probable.

18. Although U.S. dependency on crude oil imports is relaxing and may disappear, the U.S. is bound by International Energy Agency (IEA) agreements and must support its allies when crude disruption reaches 7% in any of our IEA/OECD (Organization for Economic Cooperation and Development) partners. While wrangling may be expected about trigger conditions, the U.S. will meet its commitments and will be affected by major disruptions, even after it achieves "independence" from foreign oil.

19. During a major disruption of fuel oil supplies, the Government will move to assure continuation of air service, but not to prevent decease of individual airlines. Each airline should look to the effectiveness of its individual emergency plan.

20. The present Reagan Administration favors an absolute minimum of preparation for crude supply disruptions (essentially just the SPR), and looks toward a minimum of control during crises. There are many who agree with the more moderate CSIS and NPC views: minimum government interference, but a tangible national emergency plan. Others, including influential members of Congress, seek a definitive and structured plan to override a variety of state-legislated emergency provisions which will automatically go into effect in absence of a national plan.

The Probability of Crude Oil Disruption

Having had crystal ball credibility shattered in areas such as petroleum production forecasting and pricing, it may be foolhardy to speculate about complex politics involving the Middle East and other petroleum suppliers. But, like some other fuzzy subjects which resolve into tangible options, a review of the subject may yield some useful concepts.

As in the case of future energy trends, the answers may be a matter of opinion and opinions of experts vary widely. But it is important that anyone concerned with the consequences should expose himself to the issues and that he should reach an opinion for himself. In that way, he may recognize events or trends which alter his opinion, or inputs which could either alleviate or exacerbate future energy prices.

In August 1980, the Senate reported, "The United States and our allies are likely to experience at least two more decades of vulnerability to supply disruptions, political manipulation of supplies, and periods of panic buying on the spot market." [12-5] Although the atmosphere surrounding that statement has changed considerably, it still may be completely valid.

In an unreleased study for an industrial client, the Institute for the Future (IFF) of Menlo Park, California, recently developed approximately twenty different scenarios of events in the Middle East which could significantly affect oil shipments. These included replacement of the Ayatollah Khomeini in Iran; a combination of possibilities in Iraq, with and without Iranian involvement; upsets in Saudi Arabian or Kuwaiti governments; developments in the Emirates, Afghanistan, Pakistan, Arab-Israeli relations, and so on.

The probability of any one scenario's occurring was judged to be small. But the large number of scenarios and variations, plus the expectation that there are others not presently conceivable, left the probability high that disruptions will occur. Where few scenarios may appear immediately plausible, very many are undeniably possible. In a field most difficult to quantify, it was concluded that the probability of disruption may be close to unity during any five-year period.

This conclusion checks fairly well with an earlier informal consensus from unclassified discussions with individuals from IFF, SRI International (formerly Stanford Research), which maintains a Business Industrial Risk Index (BIRI) for each nation, The Rand Corp., Defense Intelligence Agency (DIA), DOE, and the Georgetown Center for Strategic and International Studies (CSIS). In the summer of 1981, the feeling was that up to three significant disruptions would probably occur in a ten-year period. A verbal recheck in mid-March 1982 repeats the same result, plus the IFF conclusion that at least one disruption is highly probable in a five-year period.

In his just-released ***The Critical Link: Energy and National Security in the 1980s***, [12-6] C.K. Ebinger of CSIS explores many of these factors in depth. At least from verbal discussions, the others who have probed this field agree with CSIS on the significant issues. The major problems and risks are seen to be political, rather than military. It may be difficult to convince segments of U.S. society as well as Arab states that the solutions are not primarily military. It appears that the U.S. and its European partners are concerned with different initiatives. The more immediate problems are believed to be ashore, rather than in

the sea lanes ... that the shipping lanes are safe from disruption either.

CSIS also forecasts a high probability of severe oil supply shocks, with price rises similar to those we have experienced in past crises. IFF expresses it slightly differently, but agrees on the severity of the price shocks.

This author is somewhat surprised by these price-rise assessments and is swayed by our reduction in domestic oil consumption, our declining import levels, and emergence of alternate suppliers such as Mexico and the North Sea. Based on such developments, this report concludes that the next disruptions will not be as severe as those past. Rand, SRI International and some others seem to agree. But that conclusion hinges on the assumption that a complete cessation of Mideast production will not occur.

Opinion appears to split about 50-50 among foreign analysts as to whether the next disruption will be severe and cause a sharp price rise. There is no formal nor strong debate. The difference is whether a price rise will be 10-30% as some expect, or 100% as others believe certain.

Those expecting sharp price increases believe there will be major disruptions or complete stoppage at the production source. The question may be more one of whether oil production is likely to be simply suppressed by local disturbances or unfriendly regimes, or whether hostilities will get out of hand and destroy oil production completely. Or that the Soviet Union will forcibly stop production in the entire area, in preference to an overt military move in Europe.

On the optimistic side, this author also believes there should be an early increase in U.S. production capacity although, admittedly, it may now be frozen in the bud due to dropping oil prices.

Where quantified, the expectations are strong for disruptions occurring. "The chances for such a disruption — following three Mideast oil cutoffs since 1967 — are as high as 75% during the 1980s, one Energy Department study predicts."[12-7]

"Hans Landsberg of Resources for the Future says, 'No matter whether one considers consumption, production, or price, there is significant probability — some suggest that for the 1980s it should be put at 100% — that the U.S. will be subjected to major energy shocks and surprises. We seem woefully unprepared.'"

Other expressions differ in degree, but all agree that the situation is highly volatile, almost completely unpredictable, and that the combined probability of disruption is so high that the U.S. — industry and government — should plan on disruptions as a certainty. There appears to be no way to guess when the event will occur. "Overnight" is expected. "We'll know it when it's here." Guessing the rapidity of decline in supply or the depth of the disruption involves higher degrees of speculation. A majority appears to think we should prepare for sudden, unexpected, severe shocks.

In an interview by James Cook of **Forbes** magazine,[12-9] Ebinger of CSIS leaves no doubt about his concern:

"Cook: ***But what if production in the Persian Gulf were disrupted? In the past the actual shortages were generally so small as to give little cause for alarm.***

"Ebinger: We hear a lot of people say that, with U.S. oil imports out of the Persian Gulf down to less than a million barrels a day, we could live without them. This ignores the impact on our major allies in Western Europe and Japan. It also ignores the impact of interrupting Saudi production would have on global petroleum prices. Prices would soar through the roof. Since we are already in recession, it undoubtedly would lengthen or prolong it. ... worst-case scenario send us into a depression. ... would not be above the fray. You'd find the Northeast, which is more dependent on imported oil, clamoring for government to bail them out."

Among others, ***Aviation Week & Space Technology*** cautions that Soviet interest in Mideast oil is greater than simply to inconvenience or embarrass the West. ***AW&ST*** discusses this threat in, "... part of a series on Egypt's shift in technology from a Soviet to a Western orientation."[12-?]

Where we in the U.S. wonder about our eyestrain myopia from decades of Soviet watching, ***AW&ST*** notes, "Lt. Gen. Muhammad Abdel Halim Abu Ghazala, Egypt's minister of defense, said that while the U.S. has focused its attention on Europe and the threat there to the North Atlantic Treaty Organization, the Soviet Union has moved to threaten the vital oil fields in the Persian Gulf by its military presence in Libya, Ethiopia and South Yemen. This threat, Ghazala believes, also includes the pre-positioning of large numbers of fighter aircraft and armor in countries where it cannot be operated by indigenous forces because of the excessive numbers of weapons."

AW&ST details deployment of this equipment, as provided by Ghazala. "The Soviets are using a strategy of indirect approach, which officials here (Cairo) said the U.S. developed, to outflank Europe and avoid bloodshed 'in Mother Russia,' Ghazala said. He believes if the Soviet Union or its proxy forces can control Africa, they control critical raw materials required in the West for aircraft construction, and if they can control or disrupt the flow of oil at sea they can bring the West to its knees."

If the Soviet Union is intentionally planning and is successful in these moves, then we must be concerned about crude oil disruptions up to full Mideast production levels, accompanied by dramatic price rises. This author remains skeptical, but has no convincing arguments for his opinion.

Preparing for the Shock

As only a reference of what NPC has recommended at various disruption levels, their emergency scenarios[1-5] are abbreviated in Figure 12-1.

The Reagan Administration has made clear its broad policy of free markets, restraint from government controls, and disinterest in detailed contingency planning. That policy governs the July 1981 ***National Energy Policy Plan***.[12-11] And the plan's intent is borne out by the FY 1983 budget request:[12-12]

"Prior to fiscal year 1982 the Emergency Preparedness Program focused on actions designed to mitigate the deleterious effects of energy supply interruptions through Federal regulation of supply/price of crude oil and petroleum products, as well as restraint of demand within the civilian economy through a variety of mandatory conservation measures. Beginning with fiscal year 1982, the focus of the Emergency Preparedness Program has dropped this regulatory approach in favor of a program that emphasizes market response and removal of disincentives to private self-help measures. Government action could be expected only in response to extremely severe energy supply interruptions that threaten the national security and then only in a manner which assists necessary adjustments through market forces. This refocusing requires development of entirely new strategies and extensive modification of previous effort."

There is much to be said for this position. Since all agree that the nature and scope of the next disruption cannot be foretold, is it practical to devise a series of options, none of which is likely to match the events? Actual events may require actions opposite from some of the options; many energy users could be misled by planning toward unmaterialized events. And, a lack of prior commitment may permit all participants to make an even start when the event occurs.

Figure 12-1
NPC/DOE EMERGENCY SCENARIOS
APRIL 1981

CASE	LOSS MMB/D	MONTH	IEA	U.S. ACTION
1	1.0	6	NO	VOLUNTARY REDUCTION AND ACTIONS
1A	2.0	6	NO	ABOVE, PLUS SWITCHING FROM O&G TO COAL. RELAX ENVIRONMENTAL STANDARDS. INCREASE PRODUCTION; CONTROL SPEED AND THERMOSTATS.
2	2.2	6	YES	SAME, INTENSIFIED (TRIGGERED IEA UNDER APRIL 1981 DEMAND)
3	3.2	12	YES	ABOVE, PLUS PRICE
	4.6	3	YES	INDUCEMENTS, IMPORT
	3.5	3	YES	FEES OR CONSUMPTION
	2.5	6	YES	TAXES, RATIONING, DRAWDOWN OF SPR, INVOLUNTARY USE OF PRIVATE INVENTORIES

On the other hand, some basic agreements and relationships established beforehand may provide a smoother transition into the disruption mode. Some operations may proceed while details are being thrashed out. But, if there are no emergency rules at all, activity is likely to proceed until it is concluded that rules are needed, when they can be devised to meet the actual situation. There is obviously room for opinion here.

A few comments from its Energy Plan[12-11] may help to anticipate the government reaction. "Certain mitigating measures may be required from time to time to avoid unacceptable burdens in one sector or another, but these can best be considered in the context of social, not energy, policy. . . . Past U.S. energy policy relied heavily on Federal intervention, and it attempted (unsuccessfully for the most part) to protect U.S. consumers from the reality of higher world oil prices. . . . The U.S. Government is committed to increasing oil stockpiles against potential disruptions in world markets, and to eliminating controls or other impediments that could discourage the private sector from dealing with disruptions efficiently if they should occur."

"A Federal role in stockpile development is essential because — although the private sector has incentives to develop and maintain its own stockpile of both crude oil and petroleum products — commercial enterprises have no economic reason to achieve stockpile levels that are optimal from the national perspective. Under present conditions, many of the economic, national security, and international policy benefits from such stockpiles accrue to the general public rather than to investors."

"Analyses of previous disruptions of normal oil s[illegible]ly show that imposing an elaborate system of price and allocation controls only drives the social and economic costs higher." Emergency preparedness will feature:

- Primary reliance on market forces for price and allocation.
- Rapid growth in the SPR and removal of factors which have discouraged building of private stockpiles "(for example, their assumption that government will 'rescue' those who have not planned ahead if a supply shortfall should occur)."[12-11]
- Development of criteria for making the SPR available.
- Encouragement of industrial dual-fuel capability.
- Advanced planning toward temporarily increased domestic energy production.
- International coordination of emergency response.

"The Administration realizes that free markets will not work perfectly during a severe disruption. In general, however, they will work more smoothly, with greater certainty, and ultimately more fairly than complex systems of price and allocation controls managed by Government. If disruptions should occur in the future, the success of the Administration's policies should not be measured against normal conditions, but against the chaotic conditions that have been experienced. . . . If a major disruption should occur, limited Government involvement might be warranted to make sure that essential services and functions (such as those connected with national security and public health and safety) continue."[12-11]

This statement may be read that the Government will move to assure continuation of air service, but that it will not be sympathetic to demise of individual airlines. Hence, each airline should look to the integrity of its individual emergency fuel plan.

Much debate about the Administration's emergency planning may hinge on a single word in the quotation just above. "*If* a major disruption should occur . . ." For example, there are numerous popular and authoritative articles such as "Are We Prepared For Another Oil Shortage," in ***Parade***[12-13] and "Why the Next Oil Crisis Could Be a Disaster," in ***Business Week***[12-7] which strongly regard the Administration's planning as insufficient. But do they really diverge from the present plan?

In the ***Parade*** article, Tad Szulc says, "Yet ignoring all the lessons of the recent past, the U.S. could be unprepared to deal with a serious disruption in oil imports. Our stored crude oil stocks are barely sufficient for a month's consumption and — despite warnings from many quarters — neither the government nor the petroleum companies are building them adequately." The stockpile is certainly not adequate now to sustain more than a few months' disruption.

But, despite its tight budgetary situation, one of the Administration's early actions was to establish a steady input of about 300,000 BPD into the SPR, its maximum fill rate and about triple that under the previous administration. Industry reserves have stood at a record high during the past year, but are now being depleted because of decreased demand and high interest on the investment. John Berry of ***The Washington Post***[12-2] considers the same situation from a different view, "The most potent force in the market today is a huge overhang of oil stocks — estimated by some experts to be at least 300 million barrels and perhaps as much as 600 million or 700 million worldwide. Oil companies are trying desperately to reduce their stocks, but many of them, such as Standard Oil of California, have not succeeded so far." That was in March 1982. By June, much of the reserve stock had been reduced.

Tad Szulc grumbles, "As of early November, the government no longer had legislative authority to allocate in an emergency whatever fuel the U.S. does have on hand — that authority having expired on Sept. 30, with the Reagan Administration unwilling to have it renewed." The Administration obviously

has no intention of seeking such authority, but that disagreement with Szulc does not affect the thrust of his article. His primary concern is that OPEC has achieved a measure of internal price control and that this collaboration base can be used to further manipulate prices.

We need no longer speculate on the President's attitude toward energy emergency planning. On March 20, 1982, he vetoed the Standy Petroleum Allocation Act. The Act would have given him authority to set prices and allocate petroleum supplies, and would have left to him whether to use that authority. "This would, however, require that plans be drawn in advance of a crisis."[12-14] The President now has made it clear beyond any doubt that he does not wish to publish a prepared plan.

This author believes that, now that world prices approximate replacement costs, OPEC can only affect prices as much as they can reduce production. Already there are signs of severe strain within OPEC — virtually all of its members require their current income. Some, such as Nigeria and Iraq, and probably including Iran, are bordering on desperation for more income. Saudi Arabia could likely reduce production and consequently its own income, but may be loathe to jeopardize its social development to support other Arab military ambitions.

Szulc is alarmed at our vulnerable stature. He reviews some of the scenarios which could disrupt oil supply. It is doubtful anyone will disagree with his alarms. There are far less plausible scenarios which may become reality. On the other hand, Iraq has officially reported[12-15] the extent of war damage to its facilities and is plaintively outlining that five years and untold millions of dollars will be required to restore them. The OPEC meeting in March 1982 clearly shows that stresses work on the suppliers as well as on the consumers. All forces may not move in the negative direction for consumers at all times.

In *Parade*, Szulc does not propose a specific remedy; he notes that we are very vulnerable, that we have no "order of battle" for a fuel emergency, and that he thinks *we need one*. At the close of his article, under, "WHAT YOU CAN DO," he advises: "(1) Drive no more than you really need. (2) Insulate your home and office. (3) Keep thermostats at reasonable levels, summer and winter. (4) Turn off home and office lights when you don't really need them — and dim neon and other business lighting. P.S. You won't just be conserving. You'll be saving money, too."

It would be irresponsible to disagree with his recommendations. In fact, as he apparently feels, our greatest danger may be complacency during oil gluts. But, while his recommendations will further improve our situation, they could not weigh heavily in the serious disruption scenarios he expects.

It would seem unnecessarily repressive for the Government to establish contingency criteria for all combinations and permutations of possible oil disruptions. Even without their ever being imposed, anticipation of contingency regulations are almost certain to inhibit commerce. It may be on this issue that the disagreements hinge.

Ebinger of CSIS certainly proposes a minimum of government control. Although CSIS strongly favors a central SPR as being in the public interest, they do not favor government development of the policies for disbursing its contents. In[12-6] CSIS advocates a private-sector task force to administer the SPR. That may simply be a detail the Administration has not yet expressed. While the Administration plan expects, as reported above, to develop criteria for using the SPR, it does not specify that these criteria will necessarily be developed within the Government, or independent of the private sector.

The ***Business Week*** article[12-7] cautions that our next crisis may be a disaster, but it does not imply the Administration is indifferent to this risk. It notes that President Reagan declared in October 1981: "There's no way, as long as Saudi Arabia and the OPEC nations provide the bulk of energy needed to turn the wheels of industry in the Western world, that we could stand by and see that taken over by anyone who would shut off that oil."

Business Week does comment on the Administration's reluctance toward a detailed plan and points out that Senator James A. McClure (R-Idaho), chairman of the Senate Energy Committee, has proposed legislation for emergency oil allocation, reflecting, ". . . constant fear among congressional leaders that a free market approach simply could not adequately allocate supplies of oil during a severe emergency, despite criticism that an inflexible federal allocation system exacerbated 1979's shortages. . . . Administration officials counter that the U.S. is in a far stronger position today than in late 1978 and early 1979 . . ."

Business Week goes on to outline opposing views on different aspects of the federal control question. Perhaps the most compelling, which is reported at the end, is that, "More than 20 states have put forth their own programs, including gasoline rationing, to handle emergencies. Only a federal program could override those state efforts, McClure has argued, to give the U.S. a coordinated response '. . . Having the government step in to allocate again is something that no one is looking forward to,' says APRA's (American Petroleum Refiners Assn.) (Raymond F.) Bragg. 'But when you consider the pain that we'll be going through if there is another cutoff, then it starts to look like the lesser of many evils.'"

CSIS does not view controls and allocations favorably, but they see a positive need for a definitive national emergency plan.[12-6]

Ebinger points out that experience with the 1979 crisis is not reassuring; government action was not *effective and had little influence* over the basic events, which were international. "The shortage of 1979 and the 1973-74 oil embargo taught the United States several other things as well. Those crises showed that if the market system is allowed to react freely, the economic effects of a shortage will tend to be felt sooner rather than later (until the market corrects itself). Meanwhile, attempts to regulate supply and demand early in a crisis are apt to aggravate economic dislocation, not mitigate it."

But, "The lessons learned from the energy disruptions of the 1970s helped the United States keep problems in the world oil market to a minimum when the war between Iran and Iraq broke out in 1980. . . . Even so the world has yet to face a cutoff of 20 percent or more in oil supplies. The United States does not have a clear idea how it would respond to such a situation; energy planners are not even sure what constitutes a real threat to oil security. . . . Yet several independent studies have concluded that failure to develop an energy emergency planning program could ultimately lower the gross national product by billions of dollars and cause large increases in unemployment and inflation."

Ebinger points out that, "Under existing federal legislation the president has almost complete freedom to act . . ." But that then, ". . . the states must submit emergency energy conservation plans to DOE within forty-five days of the president's findings. However it is physically and financially impossible for most states to carry out the sophisticated planning required without considerable federal assistance. For every emergency measure a state considers, it must determine a vast array of facts — a determination even the federal government has been unable to accomplish in its contingency planning."

Ebinger recommends an office of contingency planning in DOE (he also recommends continuation of that cabinet-level department) to supersede all the disparate offices which have incomplete responsibilities for fragments of emergency action. The office would activate a task force with Treasury, Commerce and Transportation, supplemented by a permanent private-sector task force representing the users. This participation may require some revision of anti-trust laws. He further notes that contingency planning should reach to " . . . every level of government — federal, state and local — both to promote a wider understanding of what the energy problem really is and to develop the national consensus needed for an effective crisis response. It is time to decentralize decisionmaking, but this cannot be done without federal aid."

There is plenty of room for differences of opinion, and the NPC is clearly for a hands-off, free market. The NPC supports the Administration stand for minimum regulation, but not the concept of minimum planning. A distinction should be made, also, between those who suggest control in severe disruptions, versus controls proposed during only moderately inconvenient interruptions. The Administration appears to be in the minority in its concept of minimum planning and minimum structure to support it.

In its "Summary of Actions Recommended to Prepare for Oil Import Disruptions," (1-8) the NPC proposes:

- A government entity with senior access for planning, coordinating and administering response to major disruptions.
- A federal advisory committee from the private sector.
- Plans for effective public education and communication.
- Further studies of tax/import fee and coupon rationing options.
- Distributional measures to recycle increased government revenues during oil supply emergencies.

"The sole purpose of the National Petroleum Council is to advise, inform, and make recommendations to the Secretary of Energy on any matter requested by the Secretary relating to petroleum or the petroleum industry." (1-8) Its Committee on Emergency Preparedness, which was chaired by C.C. Garvin, Jr., Chairman of the Board, Exxon, included thirty senior executives from other oil companies, universities, and study groups. It was supported by a coordinating committee of over forty similar executives. Its conclusions should certainly be studied carefully.

At present, the Administration favors absolute minimum preparation and control: no emergency preparedness, only an SPR. There are many who agree fairly closely with the moderate CSIS and NPC view: minimum government intervention, but a specific emergency plan. Others, including influential members of Congress, seek a still more definitive and structured response. They are concerned that there is a plethora of state fuel emergency plans legislated to go into effect immediately at the onset of a crude disruption. A national emergency plan should replace the disagreements in these state actions before they are brought to bear.

Strategic Stockpiling

In addition to strategic stockpiling and emergency planning, Ebinger of CSIS(12-6) discusses other long-term measures to mitigate oil disruptions, some of which should be taken before the events occur. His discussion includes: decontrol of oil and gas prices, oil import fees, diversifying oil suppliers, developing surge capability and creating an effective response network. He also reviews short-term reponses such as rationing, fuel switching, emergency curtailment, and activity under the International Energy Agency (IEA).

Only the strategic stockpile is discussed here; the reader is referred to the CSIS study (12-6) and to the interview in ***Forbes*** (12-9) for the other subjects, including the IEA. The IEA is also discussed further in Volume 2.

Ebinger notes, (12-6) "Strategic stockpiling has long been part of U.S. defense policy; as early as 1912 President Taft set aside petroleum fields to ensure strategic stocks for the naval fleet (whence the name ***naval petroleum reserves***)." As this comment suggests, there are oil field "stockpiles" in addition to the SPR. But they can only be produced at normal oilfield rates or, in emergency, accelerated somewhat at the expense of optimum oil recovered. The same practices can be applied to other oil fields and it is debatable how they should be produced in the best total national interest.

Reserves held by industry and the SPR are the only truly available emergency supplies. The SPR is the only supply which is controlled by the government for national interests alone.

The Strategic Petroleum Reserve

The SPR Program was created by the Energy Policy and Conservation Act of December 1975 in response to the 1973-74 Arab oil embargo. The SPR Plan became effective on April 18, 1977 and was accelerated by amendment on June 20, 1977, advancing its schedule by two years and establishing a goal of 500 million barrels (MMB) in storage by December 22, 1980. Amendment No. 2 on June 13, 1978 authorized an increase from 500 million to 1 billion barrels and described plans for storing 750 million barrels in underground reservoirs by DOE. No decision has been made regarding the final 250 million barrels, which is still authorized, but currently not planned.

Ebinger points out that, "the original enabling legislation also called for the development (by no specific date) of a regional storage program for 24 million barrels, to be located in New England, Hawaii and Puerto Rico. Despite political pressure in favor of these areas, the regional program has not yet been established."

It is difficult, if not impossible, to visualize 750 million barrels of oil, or one million. Ebinger observes (12-6) that a million barrels would fill a ten-story office building with sides the length of a city block. It has been noted that one billion barrels of oil would fill the Superdome in New Orleans 45 times. (12-16) Storage of the SPR above ground would, indeed, be "something else."

The SPR is being developed in three phases, with storage of Phase I's 250 million barrels in five salt-cavern areas along the Gulf Coast in Texas and Louisiana with access to three pipeline systems. A map of the areas and their pipelines is given in Figure 12-2, taken from the SPR annual report for 1981. (12-17)

SPR Storage Capacity

To simplify the picture somewhat, charts from the NPC emergency preparedness report (1-8) have been consolidated to show only the envelope of the planned capacities for Phases I, II, and III in Figure 12-3. This figure shows that Phase I should be filled during 1982, Phase II at 400 million barrels in 1984, and the final increment to 750 million barrels in Phase III by 1989. It is also seen that there will be about a year of pause to increase capacity after Phase II is filled, before Phase III can begin.

Following the initial intentionally ambitious target of 500 MMB by 1982 and plan to accelerate to 500 MMB by the end of 1980, it was recognized in early 1979 (FY 1980 budget) that those schedule goals could not be met. It was also clear that the costs would be higher, recognizing the magnitude of some of the storage problems. The FY 1980 budget therefore proposed reprogramming of oil funds to facilities development, and oil purchases were curtailed.

By 1980, solicitation for turnkey facilities were cancelled, funding for Phase III was deferred, the 750 MMB level was delayed three years, and decisions for a fourth 250 MMB increment were abandoned. Phase I facilities were completed but left substantially under-filled and Congress rescinded $2 billion in oil purchase funds which were unused. In June 1980, the Energy Security Act required the President to increase the storage rate to 100,000 BPD during FY 1981 and beyond. The FY 1981 Appropriations Bill then required the President to seek to fill the SPR at an average rate of 300,000 BPD, or to fully use the appropriated funds.

The SPR Program inherited by the new Reagan Administration in January 1981 included: a plan for 750 MMB in storage by 1989, Phase I facilities available but under-filled, less than half the oil for 1981 under contract, and the SPR budget heavily dependent on entitlements funds from the crude oil price control program.(12-7)

Since that time, the new Administration has: awarded contracts that more than doubled the fill rate and exceeded the FY 1982 fill targets, replaced entitlements lost when oil prices were decontrolled, and requested EPA to permit a faster leaching rate at Bryan Mound to increase storage by 50 MMB in 1985. In August 1981, SPR oil acquisition was placed off-budget.

Highlights of the present program(12-12) include: Storage will increase from 251 MMB at the end of FY 1981 to 267 MMB at the end of FY 1982 and 343 MMB by the end of FY 1983. Phase II was increased by 40 MMB and Phase III (dropped to 210 MMB to hold the 750 MMB total) development begins during the year. The present budget request allows the SPR to fill all available permanent storage capacity in FY 1983 and to average about 200,000 BPD during the year.

The ***Kiplinger Washington Letter*** of April 9, 1982 reported, ***"Gov't is stockpiling more slowly*** in its salt-dome reserves, even though prices are way down . . . 186,000 barrels a day are pumped in, compared with 318,000 a day last year. Tight budget is the main reason." Their information did not come from the DOE Deputy Assistant Secretary for Strategic Petroleum Reserves. His office advises that, in actuality, 335.8 million barrels were added during 1981 (batting above 300!).

From January through April, 1982, the fill rate dropped to 205 million barrels per year because of limited storage capacity, not from budgetary limitations. DOE is seeking additional interim storage capacity until the permanent space is made available in the salt caverns. Storage capacity will remain the limitation for the remainder of 1982. As of June 1982, the SPR in storage had passed the 260 million barrel mark.

SPR Drawdown Rates

Although allocation and distribution policies for using the SPR have not been defined, the rates of drawdown and feeding into the pipeline network appear effective to the author, as shown in Figure 12-4. It appears (to this author) that alarming statements such as made by Malcom S. Forbes in March 1981 are unproductive. He said on his editorial page, "No matter what — we'd better start pouring, instead of dribbling, oil into that clump of strategic oil reserve salt domes in Louisiana. Since the program was established six years ago, we've put in about a week's worth. At the present rate it would take 15 years to stockpile the billions of barrels required if we're to have three or four months' worth on hand."(12-18) His feeling of urgency is warranted; his suggestion that the fill rate must be increased was unrealistic. Apparently he did not recognize that the full fill rate had been achieved and was holding at that time.

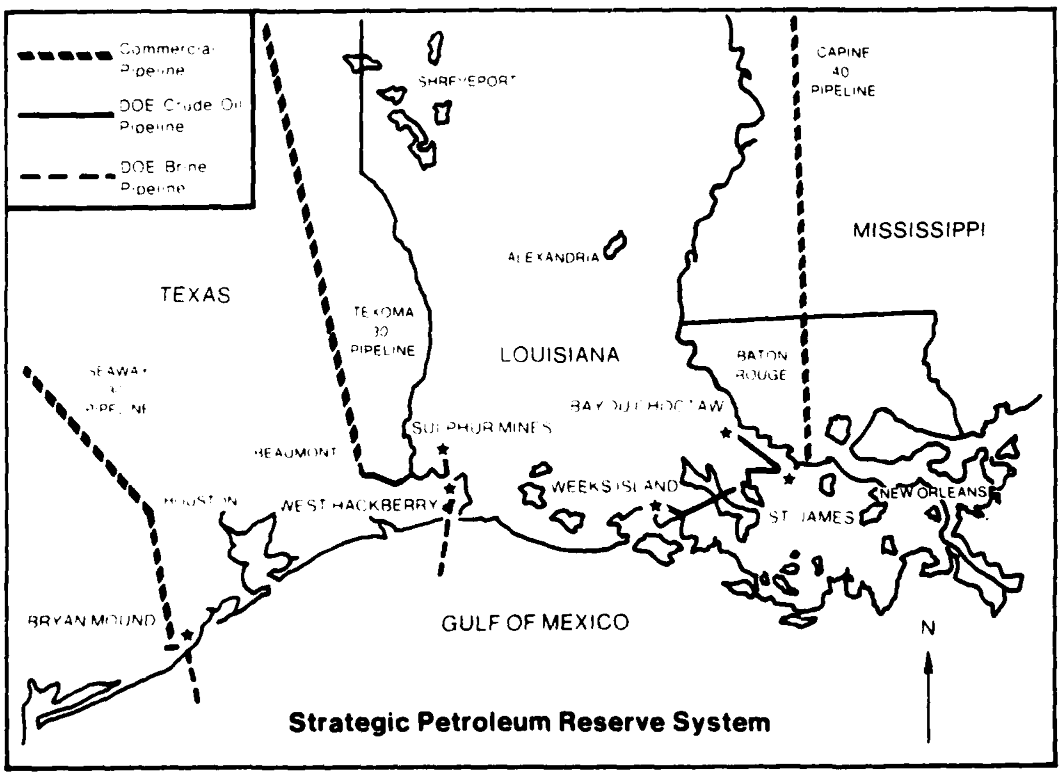

Figure 12-2

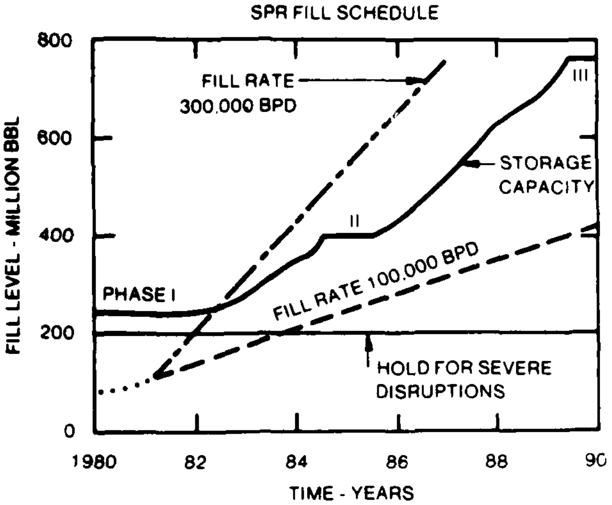

Figure 12-3

At the end of Phase I, essentially where we were at the end of the first quarter of 1982, the drawdown capacity was almost 2 MMBD. Recalling Ebinger's building ten stories high and a block on each side, filling two of those tanks per day with a million barrels each suggests impressive pumping capacity. Equally impressive, SPR supply at that rate for over 60 days, and at half that rate after 120 days would appear to offset a large share of the potential disruption threats which we must face.

However, recalling that the NPC strongly recommended we not permit our SPR reserves to fall below 2 MMB (as a bedrock protection against unexpected disaster or active war) we are only beginning to fill the SPR portion available to relieve "normal" crude disruptions, and we won't really reach an effective capacity until Phase II is completed in 1985. But, at that time with 400 MMB in the reserve (200 MMB available for distribution) and with a drawdown capacity then of 3.5 MMBD, we should be in relatively good shape for anything short of a complete shutdown of Mideast production for more than four months.

Our net condition, as Ebinger pointed out to Cook,[12-9] will still be dependent on how our IEA allies fare and what their reserve conditions are at the time.

SPR Politics and Financing

Although SPR circumstances appear encouraging and tranquil at the present, there are objections to the present program and even it could go awry. One of the reasons filling proceeded at such a slow rate earlier is that Saudi Arabia strongly objected to our SPR plan. In the tight market, others, including Americans, felt that filling the SPR simply added to demand and pushed prices further upward. Some of those objections were relieved by the recent glut conditions.

"A long-term commercial contract was signed on August 20, 1981 with Petroleos Mexicanos (PEMEX), Mexico's state-owned oil company for purchase of approximately 110 million barrels of crude oil through 1986."[12-17] While Saudi Arabia may be displeased, they can scarcely condemn a bilateral agreement which involves neither them nor their sales to the U.S. Of course, it easily may be argued that they had no basis for objecting to our stockpiling Saudi oil, although they implied at the time that their price was set as a favor to U.S. economic stability, not to be used as an SPR weapon against OPEC.

In a slack oil market, OPEC and Saudi Arabia now may encourage purchases for all purposes, including stockpiling. Mexico also may be pleased now, with a guaranteed price under our long-term contract. Objections to the SPR may increase within the U.S. if it turns out our purchases from Mexico could be made on the spot market at lower prices. But insurance can never be bought at optimum prices. As Ebinger remarks, *insurance only pays off handsomely in case of disaster.*

With SPR financing no longer provided by entitlements and with desire to keep the purchases off-budget, there may be increasing pressure to involve the industrial community in SPR financing. Ebinger points out that the U.S. is, strangely, the only OECD country with a fully federal-financed program. "In Japan, for example, some reserves are maintained by the government and some are held commercially. Germany and the Netherlands permit special corporations to control reserves. In France and Italy the oil companies manage the entire strategic reserve program. Only in the United States is the reserve solely under federal control."

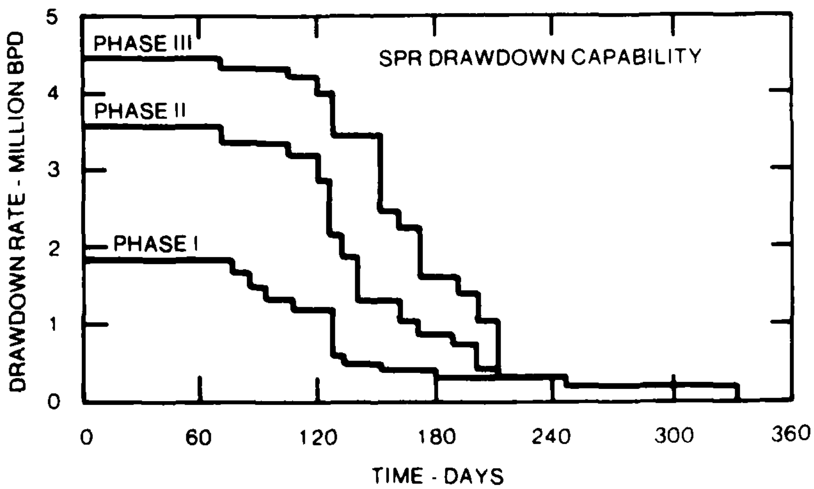

Figure 12-4

While this may appear a perplexing U.S. leaning toward socialism, it no doubt stems from strong U.S. anti-trust sentiments.

John Lichtblau, executive director of the Petroleum Industry Research Foundation, Inc., is quoted, "The administration's most important task in the area of energy policy is to protect the nation from external interruptions and their economic consequencies. If this is recognized, the idea of private financing becomes as unreal for the SPR as it would be for defense expenditures."[12-9] Lichtblau recommended at a Senate subcommittee hearing that another tax on gasoline and highway diesel fuel be added to finance the SPR, calculating that a 4-cents/gallon tax would pay for the 300,000 BPD fill rate. There are some indications that this approach is receiving serious consideration.

Others have suggested issuing bonds to make the purchases, backed by value of the oil. But Michael T. Welch of Citibank comments[12-9] that only speculators would buy them. "Oil would have to appreciate to $120/bbl during the next 10 years for the bonds to beat some corporate bonds." Robert F. Dall of Salomon Bros. proposes a Strategic Petroleum Reserve Corporation, with an off-budget, federally-operated charter. It would raise the funds through 10-year bonds, backed by Treasury credit.

Some have suggested that Synthetic Fuel Corporation funds could be used as backup for the SPR.[12-9] Synthetic fuel interests counter that the existence of an SPR is already a threat to the future of a synthetic fuel industry.

At least we are now discussing how the SPR program will be completed, rather than whether we will do it and when we will get on with the job.

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Appendix A

Glossary

ACEE	NASA's Aircraft Energy Efficiency development program.
AGA	American Gas Association.
AHEG	Ad Hoc Executive Group (in the international Hydrogen in Air Transportation organization).
AIAA	American Institute of Aeronautics and Astronautics.
AIChE	American Institute of Chemical Engineers.
API	American Petroleum Institute.
APU	Auxiliary power unit — supplies power to aircraft on ground.
ASM	Available seat-miles.
ASTM	American Society of Testing Materials.
ATA	Air Transport Association.
ATC	The U.S. air traffic control system.
BBL	Or bbl, barrels.
BIRI	Business Industrial Risk Index (SRI International).
BOE	Barrels of oil equivalent energy.
BPD,bpd	Barrels per day.
BRB	Board Room Briefing, at beginning of each chapter.
CAL	Continental Air Lines.
CNG	Compressed natural gas.
CO_2	Carbon dioxide.
CRC	Coordinating Research Council (aircraft fuels).
CSIS	Center for Strategic and International Studies, Georgetown University.
DOC	Aircraft direct operating costs (ATA method).
DoD	Department of Defense.
DOE	Department of Energy.
DOT	Department of Transportation.
EEC	European Economic Commission.
EOR	Enhanced oil recovery, tertiary recovery.
FAA	Federal Aviation Administration.
FRG	Federal Republic of Germany, West Germany.
FSS	Flight Service Stations (part of ATC).
FY	Fiscal Year.
GA	General aviation.
GAMA	General Aviation Manufacturers Association.
GDP	Gross domestic product.
GE	The General Electric Company.
GNP	Gross national product.
GRI	Gas Research Institute.
GURC	Gulf Universities Research Consortium
IATA	International Air Transport Association.
I.C.	Internal combustion engines.
ICAO	International Civil Aviation Organisation.
ICBM	Intercontinental ballistic missile.
IEA	International Energy Agency (OECD nations).
IFF	Institute for the Future.
IGT	Institute of Gas Technology.
IIASA	International Institute for Applied Systems Analysis, Laxenburg, Austria.
ILS	Instrument landing system.
INS	Inertial navigation system
IOC	Indirect operating costs (ATA method).
LCH_4	Liquid methane, liquid natural gas, LNG.
LDC	Less-developed countries, Third World.
LFC	Laminar flow control (of aircraft skin friction).
LH_2	Liquid hydrogen.
LNG	Liquid natural gas, liquid methane, LCH_4.
LPG	Liquid petroleum gas, propane, butane, etc.
MHD	Magnetohydrodynamics, electrical generation *using a stream of ions in a magnetic field.*
MIT	Massachusetts Institute of Technology.
MLS	Microwave landing system.
MMB	Million barrels (M being one thousand in Roman).
MMBD	Million barrels per day, sometimes mBD or mbd.
MMBY	Million barrels per year.
NAA	North American Aviation (now Rockwell Int'nl.).
NASA	National Aeronautics and Space Administration.
NGPA	National Gas Policy Act of 1978.
NO_x	Nitrogen-oxygen compounds, x denoting any of several.
NPC	National Petroleum Council.
NWS	National Weather Service, of the National Oceanic and Atmospheric Administration.
OAPEC	Organization of Arab Petroleum Exporting Countries.
OCS	Outer continental shelf
OECD	Organization for Economic Cooperation and Development.
OPEC	Organization of Petroleum Exporting Countries.
ORI	Operations Research, Inc.
OTA	Office of Technology Assessment (U.S. Congress).
OTEC	Ocean Thermal Energy Conversion.
PRC	Peoples Republic of China.
psi	Pounds per square inch.
PURPA	Public Utilities Resources Policy Act of 1978.
Quad	Quadrillion Btus, 10^{15} Btus, about 172 million barrels of oil, 44.4 million short tons of coal, 293 billion KWh, or 1 Tcf of natural gas.
R&D	Research and development.
R&E	Research and engineering.

RFF	Resources for the Future.
ROI	Return on investment.
S.I.	Spark-ignition engines.
SPR	The U.S. strategic petroleum reserve.
SRI	Stanford Research Institute.
STC	Supplemental type certificate (aircraft).
SWRI	Southwest Research Institute.
Tcf	Trillion cubic feet (natural gas).
TEL	Tetraethyl lead.
TJ	Terra-Joule, trillion Joules, 10^{12} Joules, about one billion Btus
UGR	Unconventional gas recovery.
USAF	U.S. Air Force.
USGS	U.S. Geological Survey, Department of Interior
VTOL	Vertical take-off and landing aircraft
WEC	World Energy Conference.
WPT	Windfall profits tax.
WWI, WWII	World Wars I and II.

Appendix B

Acknowledgements

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C.L.B.

Appendix C

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Agenda

CSIS-FORUM

Aviation Fuels - October 20, 1981

Conference Room, Third Floor, International Club
1800 K Street, N.W. Washington, D.C. 20006

Chairman: Charles K. Ebinger, CSIS
Director, Project on Energy
and National Security

8:45-9:00	Coffee and Danish
9:00-9:15	Welcoming remarks. The CSIS Project on Energy and National Security: Charles K. Ebinger, CSIS
9:15:9:30	The Mellon Institute's Least Cost Energy Study. General Outlook for U.S. Transportation Energy: Richard H. Shackson, Mellon Institute
9:30-11:00	The Impact of Petroleum, Synthetic and Cryogenic Fuels on Civil Aviation: C. L. Blake, Federal Aviation Administration
11:00-11:30	General Discussion
11:30-12:30	Lunch: The Board Room
12:30-1:30	Jet A Specifications, Availability and Costs Kurt A. Strauss - Texaco, Inc. S. V. Drum - Chevron, U.S.A., Inc. William G. Dukek - Exxon Research and Engineering Albert Momenthy - Boeing Commercial Airplane Co.
1:30-1:50	Discussion
1:50-2:35	Petroleum Resources and Production Oswald Girard - U.S. Geological Survey Theordore R. Eck - Standard Oil of Indiana Joseph D. Parent - Institute of Gas Technology

2:30-2:50	Discussion
2:50-3:00	Coffee Break
3:00-3:15	U.S. Shale Oil Outlook Paul A. Petzrick - Department of Energy
3:15-3:30	Discussion
3:30-3:45	Fuel Conservation in Air Traffic Control Siegbert B. Poritzky - Federal Aviation Administration
3:45-3:55	Discussion
3:55-4:10	International Interest in Hydrogen G. Daniel Brewer - Lockheed-California Co.
4:10-4:20	Discussion
4:20-4:30	Closing Remarks: C. L. Blake Charles K. Ebinger

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Aviation Fuels - October 20, 1981

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Synopsis of Tapes: CSIS Forum on Aviation Fuels, Oct. 1981

C. L. Blake

Dr. Amos Jordan, V-P and Chief Operating Officer, CSIS: Greeted the group and invited them to seek new ideas in the meeting. Outlined CSIS activities in Energy: The famous Bridges 3-D model which has been used in briefings on Capital Hill; an energy film seen by about a million people on TV; several volumes, including a massive three-year study on coal, ended last year. Present work includes a nuclear study under Rodney Jones, a non-proliferation expert; an oil-field security study by Maza Hamid; a new study on Energy in the Patterns of Power in the Persian Gulf; energy in the Southeast Asian studies program under Swinch Price; a full version of the study on Venezuela; and energy in a study of the whole of Alaska in the 1980s.

Energy permeates a half dozen of current CSIS studies, the primary of which is on Energy and National Security, a broad look at the role of energy in the international arena, headed by Dr. Charles K. Ebinger.

Dr. Charles K. Ebinger, Director, Project on Energy and National Security: Since the Center is a public policy institution, comments on the elements of the presentations and discussions which have a bearing on public policy, will be particularly appreciated. Is there a role for the Federal Government, a piece of legislation that needs enactment, or other factors which might be hindering our supply of aviation fuel for the future?

Richard H. Shackson, Assistant Director for Transportation, The Mellon Institute: For the past three years, Mellon has been looking at the US demand in Btus, considering what we define as "Energy Service", the amount of heat, light, cooling or ton-miles that you get for your energy. In the annualized cost, we include costs of all the capital equipment which may be used in converting that energy into its useful forms. The thrust of our study has been to see what could be done to minimize the cost of energy, assuming that everyone has access to capital and will make good choices. This is not a forecast; it leads to a boundary of what might be achieved and some of the options that can be considered.

Assuming a 2% GNP growth rate, we are still able to retain energy demands at or below today's level. Much of the reduction is in oil, which is released by the transportation market, mostly by improvements in efficiency, dominated by autos and trucks. This is what we see in a perfect market, where the investment gets paid under cost recovery.

We looked at the Year 2000 situation with two scenarios, including the possible use of methanol, as opposed to converting all the synthetic fuel into gasoline. We see a replacement of between 2 and 3 million BPD attributable to

transportation and another 2 million through stationary systems. The important thing is that there are options for providing more fuel to aviation. These represent boundary conditions, not predictions. Blake's work, being more predictive, must stand the scrutiny of probability.

Q-What were price assumptions in 1990 and 2000 in terms of 1981 dollars?

A-In '79 dollars, these were the price forecasts made by EIA. We have made sensitivity analyses. We see natural gas claiming a very large industry share, with prices moving more as a function of coal than as a multiple of oil. After the next ten years or so, natural gas and oil will not be competing for the same markets.

Charles L. Blake, Federal Aviation Administration: Two sections to the report: First, on the price and availability of aviation fuel and the factors affecting price---the economics of fuel, by far the larger part of the report. Second, on the disruptions to imports of oil, probability, duration and effects. The second section is not much more than a postscript.

Under economics are included the supply and demand sides. Demand is essentially conservation, which can come from operations, the ATC system, the aviation weather system, and from aircraft design. While the whole story here on aviation fuel economics involves a bewildering array of subjects, it is important to see the whole picture at one time in order to get a full perspective and to see the interrelationships.

The past five years have seen more increase in aviation fuel demand than is expected in the future. Although jet fuel demand will increase, on the national scale the increase in percent jet fuel to national petroleum increases far more, because total petroleum is falling off, rather than because of the increase in jet demand. Imports have also been falling off rapidly.

In a period of rapid transition, it is unusually difficult to forecast with any confidence, and individual forecasters today are concerned that they are probably affected too much by the conditions of the moment.

Length and destination of the "energy transition bridge". The IIASA Study (International Institute of Applied Systems Analysis). The fifteen-year visibility barrier: a survey of numerous studies from many countries on many subjects shows that, if a study projects beyond a 15-yr period, almost invariably there will be an unexpected or inconceivable occurrence which will affect the outcome of the study more than any of the major components in the study.

IIASA concluded that 50 years was insufficient to achieve a world energy transition---institutional and capital-expense problems cannot be solved in that period of time. Concluded transition more like 70 years. The world problem now is liquid fuels and is likely to remain the problem. If industrial countries could give the Less Developed Countries (LDCs) all the nuclear powerplants they need to generate electric power, neither the LDCs nor the industrials could afford to supply the electrical distribution or storage systems which would be required to supply the power where needed. The same applies to photovoltaic cells or other power-generation systems. If

industrial nations gave the LDCs photovoltaic cells free, they wouldn't be able to afford the concrete, steel and controls for installation, as well as the electrical distribution systems.

Liquid fuel systems are the cheapest and the only ones the world can afford in the quantities required. Today's petroleum in the liquid system may later be supplanted by methanol and, finally, by hydrogen. Coal and nuclear power should be used more, in the long run, for producing liquid fuels than for heat or producing electricity. The technology and the economics of this energy transition will be feasible, but the international, political and sociological problems will be extremely difficult. Carbon dioxide will double in the atmosphere by the year 2030.

Discussion of M. King Hubbert statistical theory of oil depletion shows that the data are strong and consistent---any statistical analysis will conclude that the peak of US oil production occurred in 1970. If the future follows the same statistics, that rate will never be repeated; US oil production must inevitably decline into the future. The question is whether the past was actually governed by statistical characteristics---was truly a random process---and whether the future will be governed by the same influences.

Pointed out effects of taxes as a disencentive to finding or reporting oil. Oil prospecting has not had free access to federal lands. There may (and should) be a significant effect of the increase in oil prices since 1962---all the earlier analyses came from a history of stable, low prices for crude oil. Due to the 10.5-yr lag between oil discovery and production, the effects of the 1973-74 price rise have not yet been fully felt. The effects of the 1979 price rise are only getting into the discovery mode at this point. It appears the past was not truly statistical and that, particularly, the future need not be goverened by the same forces.

But the thing that is important is not the quantity of new oil that will be produced; it is the price. If the means for new production is expensive, there may be no price relief for aviation, even though petroleum may be available in adequate quantities.

Enhanced Oil Recovery (EOR) has significant potential for production. About 30-35% of the oil known in depleted fields has been extracted and at least 10-15% more can be extracted by EOR. But costs are high, while taxes and regulations are unfavorable. The important thing about EOR is that it is here and now; if favorable political and economic conditions can permit EOR to be produced at a competetive price, the steps should be taken as early in this decade as possible.

Producing Jet A to the existing specification limits could increase the yield from a barrel of crude oil by 40-50%. Since Jet A is often supplied from stocks that also supply home heating oil and boiler oil, the flash point limits imposed on those other fuels by local safety regulations may govern the limits of jet fuel deliveries, rather than the jet specifications. Lowering the freeze point of the spec has adverse effects on aircraft operation and fuel consumption, with greater effects on the new generation of aircraft than on the ones now in service. An increase in the aromatic content of fuels has a similar adverse effect. Accepting a heavier fuel may negate much of the advance in lighter weight, better life, and decreased use of strategic

materials that have been achieved in aircraft engine development over the past several years.

Discussed some of the potential of natural gas in backing petroleum out of the stationary power market, by direct use as compressed or liquified fuels in other transportation, as a source of hydrogen in refining or improving aviation fuels, or, conceivably, as a direct cryogenic fuel in aircraft operation. Natural gas is demand-limited in the US today; it suffers from adverse regulations and taxes. Natural gas is a legal and institutional problem, rather than one of resources, supply or technology.

The US fuel problem is not at all its resource supply quantity, but the production rates and prices that can be achieved. Compared the delivered prices of various alternative fuels. Shale oil is the lowest-priced alternative to petroleum crude and requires less energy to produce per gallon of jet fuel, while it naturally has a low aromatic content. Coal distillates, on the other hand, produce a high-quality gasoline, but not directly a good jet fuel. Shale also produces from 40-70% yield from the barrel and, with more hydrogenation at a cost of about $1 more per barrel, can literally go to 100% jet fuel produced per barrel of shale crude. Shale crude can be available from five to ten years earlier than coal liquids (as opposed to coal gas conversions).

DOD has made a conclusive decision on future fuels, selecting shale crude as their source of alternative fuel, over EOR, tar sands and coal. DOD concludes that liquid hydrocarbons will power their equipment for the foreseeable future, that shale will replace their need for petroleum. DOD will not sponsor shale oil production, but will concentrate on converting the oil to fuel and on the suitability of that fuel in their military equipment. The Air Force has had a very successful program with three contractors refining shale oil into jet fuel. The yield was high, the quality was very high, and the costs were reasonable.

Industry projections on shale oil production are encouraging, about 700,000 BPD in 1990, and as high as 4-6 million BPD by 2000. With about half-and-half shale and liquid products from coal, the US could produce as much as 15 million BPD by 2015. Capital investments for shale production are much higher than for onshore Alaska or for North Sea oil operations. In all of the alternatives to petroleum, the capital costs turn out to be about 3/4 of the total costs of producing fuel. Infrastructure and peripheral costs will probably be greater than the basic costs. Within the industry, the infrastructure is generally regarded as a larger problem than the direct production of fuel.

Aircraft designed to operate on cryogenic fuels are slightly smaller than for jet fuel, but the aircraft and direct operating costs are directly comparable. The costs of cryogenic liquifaction plants at airports add a considerable capital cost to the cryogenic fuels. While jet engines will operate well or better with cryogenics without modification, the aircraft fuselages would be considerably different to house the insulated tanks within the fuselage. Realizing the total potential from cryogenics requires a new airplane. Cryogenic aircraft would have smaller engines, make less noise, and produce considerably less exhaust emissions. If the low temperatures can be applied at the skin of the airplane to achieve laminar flow, approximately 25% further

fuel economy might be realized, but requiring very advanced technology. Contrary to the popular aversion to hydrogen publicised by the Hindenburg disaster, liquid hydrogen is relatively safer than jet fuel to passengers in a survivable crash.

Production of any alternative fuels from shale, coal and other hydrocarbons releases considerable carbon dioxide to the atmosphere, while burning all of the fuels ,except hydrogen, releases additional carbon dioxide. Hydrogen produced by electrical means releases no CO_2, while burning hydrogen, of course, produces no CO_2. If the greenhouse effect and future carbon dioxide become important, then hydrogen will become a significant candidate fuel, on a world scale, not just in aviation.

A recent proposal to DOE would have delivered liquid hydrogen to Los Angeles Airport at a lower price per Btu than Jet A. the low price was achieved by selling electrical power and other energy byproducts at favorable prices. Although the proposal was not accepted, it made the important point that industrial and economic developments may play a more significant role in the relative price attractiveness of various fuels than technological developments.

Conservation is about the only avenue through which aviation activities can affect their fuel demands. A 2% saving in annual fuel use would have cancelled the 1980 airline financial loss. Aviation fuel saving is not important to the national fuel picture, but fractional percentages of fuel savings are important to airline profit and loss statements. Airlines have made great strides in saving fuel since 1973; together with changes in FAA air traffic control procedures and practices, the total savings achieved in gallons per passenger-mile have been about 43%. Some airlines have gone to great lengths toward saving fuel. An Aerospace report to DOE tabulated "47 Strategies" for saving fuel in aviation. Many of the recommendations made in this 1978 report have already been achieved, but some steps remain for exploitation.

The aviation weather system offers the potential of about $300 million savings in fuel per year for a one-time investment of $1 million and an annual operating expense of $600,000. This is a real bargain that FAA and NASA are pursuing. It deserves strong attention and vigorous support.

Additional savings of up to 50% in fuel conservation can be saved in new aircraft designs. This level of economy requires synthesis in new aircraft, rather than by retrofit, although substitution of new engines provides the major part of the saving. Airlines will need impressive financing for the capital to convert to fuel-efficient fleets.

The US has reduced its dependence on foreign oil to about 35% of its oil consumption but, at this level, is still highly vulnerable to disruptions of foreign oil imports. The Senate expects about two more decades of vulnerability; foreign affairs analysts expect about three serious oil import disruptions in any ten year period. A National Petroleum Council report on oil supply disruptions is their recommendation to the DOE and has not received approval from the Administration; it is yet to be debated in Congress. But it is a valuable reference and may be a pattern for future decisions. NPC recommends that the free market forces should prevail at all levels of

disruption. The Government should intervene only in case of sudden shocks to which the market cannot respond quickly, or severe dislocations of the national welfare. Normal user/supplier relationships are expected to prevail and to govern supply channels. NPC also recommends no price controls throughout.

A short review of the Strategic Petroleum Reserve was provided, showing that the US is now filling at an effective rate of 300,000 BPD, purchasing from Mexico. Even so, the SPR cannot be used effectively until after 1982, while the NPC recommends that the SPR should hold a minimum of 200 million barrels for completely unforeseen contingencies. By the 1987-88 period, the SPR should become a significant factor, not only toward protection against disruption of foreign imports, but as a stabilizing factor in world market prices. The normal US petroleum refining and supply system is a through-flow system, which does not contain additional effective reserves. Whatever excess it contains at any one time is required for the normal ebb and surge in the system and should not be considered divertable in emergencies. The only reserves effective in emergencies are the SPR and stocks that are privately held.

The NPC noted that the US aviation system is essentially self-regulating in emergencies because slowdown in the GNP and industrial activity, as well as in discretionary income, automatically restricts travel. They also observed that airlines have already taken strong steps in fuel conservation; there is no point in additional urging from the Government or others. The only step they would suggest in at least a moderate fuel oil disruption, would be an increase in passenger load factors up to 70-75% by increasing seating density, doubling-up on flights, and some flight cancellations.

The NPC concluded that US refinery capability is adequate to produce the desired product slate for all the disruption scenarios, without any assumed alteration in fuel specifications.

CONCLUSIONS:

For Aviation:

1. Motor transport fuel and stationary power fuel will influence the price of aviation fuel more than will aviation activities.

2. Delivering Jet A fuel to existing spec limits should increase yield, if it can be done, should reduce refinery costs and could reduce fuel prices. Lowering the flash point should further relieve refinery operations and will not hamper aircraft operations, but a test program should investigate the effect on safety.

3. Raising the jet fuel freeze point or aromatic content indicates significant aircraft operating penalties, particularly for newer, fuel-efficient airplanes. The aircraft and engine costs for accepting fuels with higher freeze point or aromatics must be balanced off against long-term forecasts of reduced fuel prices. These prices must also consider the intrusion into other fuel markets, such as diesel fuel, and consequent effects on price.

4. Aviation users may wish to encourage more refiners to produce jet fuel. Or they may wish to promote a trading in crude stocks, so that refineries which are producing jet fuel would trade to get more suitable stock from the much larger number of refineries which do not produce jet fuel.

5. As petroleum prices rise, shale oil offers the best alternative for excellent Jet A at competitive prices. Aviation customers should promote the use of shale oil exclusively for jet fuel production, rather than have it mixed into the normal refinery streams, as will otherwise probably occur.

6. Crude oil import disruptions will reduce aviation traffic and raise fuel prices. These disruptionns are strongly probable and minimal federal government intervention has been suggested. Aviation fuel users might want to consider private contingency arrangements for these cutoff probabilities.

7. US refinery flexibility is adequate to meet all crude disruption scenarios without changing the fuel specifications.

8. The strongest effects on US energy and on aviation fuel prices will probably come from US regulatory, tax and land policies.

9. World interest in aviation hydrogen could be accelerated by economic and production developments or by carbon dioxide influence on the greenhouse effect.

National Conclusions:

1. For the next twenty or thirty years, petroleum fuels will be generally available and prices will be determined by competition in the marketplace. Production costs will increase with difficulty of extraction and treatment and real prices will therefore rise at up to 2% per year.

2. Regardless of the sources of liquid fuels in the US, capital investments will increase substantially. All alternatives are capital-intensive. Natural gas may offer the greatest amount of energy per dollar of capital expended. The outcome is more dependent on public policy than on physical technology or on economic forces.

3. US crude oil imports will probably be disrupted some three times in a ten-year period. The SPR will provide no cushion until after 1982 and will become significant in about 1985-87. During these supply disruptions, conventional market forces and relationships will prevail. The Federal Government will intervene only to correct severe national dislocations. (However, Congress has not yet endorsed this policy, so it is not firm). Fuel users, such as airlines, should establish their own supply lines or reserves for emergencies.

4. US public land policies, regulatory policies and tax policies will decide the US energy future far more than any other forces.

Global Conclusions:

1. Energy transition will continue indefinitely as energy sources and forms compete in the market, while production and conversion costs will increase erratically.

2. No single energy system will dominate the future world market. A variety of sources and systems will prevail, dependent on local conditions and economics.

3. Electrical transmission and storage costs limit ultimate spread of electricity. The major form of world energy now is liquid fuel; liquid fuel will continue or even increase in importance in the future. The petroleum distribution system may later carry methanol and, ultimately, hydrogen. Coal and nuclear power may ultimately produce more liquid fuels than electricity or heat.

4. Atmospheric carbon dioxide is expected to double in the next fifty years. Initial comprehensive studies of the possible consequences will not be available for another one to two years. Experimental evidence to check these analyses probably will not be conclusive for at least twenty years, if then.

Ebinger: Some items of interest to the Center he hopes we can get on the table:

While the relationships of supply/demand/price have been discussed, the problems of infrastructure have been indicated as major, but have not been explored. What ensures that the necessary decisions for these problems will be made, either by Government or by local communities, if we are going to get some of the synfuel plants going?

While some of the projections such as for synfuels are made by some of the people in this room, these projections seem to be receding farther over the horizon. Recalled that at DOE there was a time when it was thought that if the price of crude oil went to $7 per barrel, we should be able to get all the shale oil we want. Some of the price forecasts seem to assume a constantly rising price for oil, or at least they look better if the price of oil continues to rise. How do they look if oil prices stabilize for a period, or if they slightly decline, even though we may not feel that is a probability?

The future of hydrocarbons in the US and the effect on aviation fuels remains highly problematic. Considering that some 70% of our OCS resources are offshore Alaska, we must be concerned about the accessability constraints, the environmental constraints, the legal constraints effects on production dates, even with the more liberal policies of the new administration.

What is the role of US Government policy, particularly in the area of synthetic fuel development? If, after promoting start-up of an initial synthetic industry, the Government does not follow up on loan guarantees and other incentives, what will be the effect on synthetic development? What do some of the industry representatives present think might be done to stimulate and sustain the synthetic program?

Noting that US refinery capacity has been indicated adequate in case of crude oil import disruption, what will be the effect if giant OPEC export refineries and pipelines, or other planned producers such as Mexico, tie their oil deliveries to our acceptance of so much refined product? In that climate, would we still have the flexibility to meet the variety of contingencies?

Until we remove the restrictions on natural gas and, indeed, remove all the restrictions and subsidies on forms of energy, how realistic can our

comparative forecasts of competitive fuels actually be? Will t real-life policy world permit us to make the choices that the market would indicate?

Q- Where did the projection on motor gasoline come from?

A- That was an actual, rather than a projection and it came from the EIA 1980 Summary. It was the amount produced, not necessarily consumed. For example, there was an increase in jet fuel stock during that year.

Ebinger (to Questioner)- Did you find those unusually high?

A- No, unusually low.

Momenthy- There is no aircraft spec on flash point; we seem to confuse between aircraft specifications and purchase specifications.

The proposed increase in load factor during fuel disruptions would not be reasonable because of the variety of routes. Aircraft for the year 2000 have already been sold; we have already made the decision of what fuel will be used in them. Extremely high aromatics or freezing points are somewhat academic. Would like to know whether the costs for hydrogen-powered aircraft came from the NASA studies or more recent. They are highly imaginatative, certainly not correct. Would like to see some cost results from a real in-depth study of hydrogen and hydrogen-fueled aircraft. NASA identified their study as first-cut preliminary design. Those data should not be compared with today's aircraft.

(Several minutes of inaudible conversation, by Dr. Shank of Pratt and Whitney. The following is very brief, from notes): As Momenthy said, the choices have been made for aviation fuels past year 2000. Aircraft have a long service life or depreciation period and the intervals between maintenance have been growing longer. EPA emission requirements have cost P&W $100 million, with no increase in productivity. Present combustion efficiency in aircraft turbines is between 95.5 and 95.6%. New combustors to accept heavier fuels would cost $100 million to develop and produce. Modifying turbines would be even more expensive. The cost of developing a new engine is about $1 billion, about the net worth of the company. Most of the cost of a new engine is in the hot section and in the high spool, which are the areas requiring redesign for a change in fuel.

Ebinger- When you design these new engines, do you make specific assumptions about future fuel prices?

Shank- No, not specifically, but heavy emphasis is placed on fuel economy. Before fuel price became so important, we have always been concerned about fuel consumption because of its effect on performance--range and payload. (Additional inaudible).

Shackson- Although the development cost of a new automobile engine isn't as high as the $1 billion for the new aircraft engine, the tooling and equipment for the production rate brings the total investment for a new car engine up to the same $1 billion level.

Brewer, Lockheed- NASA has recently awarded contracts to both Lockheed and

General Electric to study the effects and costs of using broad-spec fuels in aircraft.

Borger, Pan Am- Airlines did not commit to buying jet aircraft just because they were faster; it was because they were able to offer a lower DOC in cents per seat-mile. Putting more seats in an airplane is the quickest way of getting lower fuel burned per passenger-mile. Also use larger aircraft.

Dr. Lander, USAF- Petroleum has been a big factor in the development of aircraft, the fact that it has optimum energy density. The Air Force is dependent on continuing use of this high-quality fuel. If we could get low-priced hydrogen, we could manufacture a variety of alternatives. We might use special fuels for very special missions and requirements, but the bulk of our needs will be met with petroleum-like fuels. Shale oil is a good source for middle distillates, not just for jet fuel. We are concerned, as all engineers and scientists should be, about the potential greenhouse effect. We are bullish on shale oil because it is an attractive hydrocarbon which is very similar to what we use today. One of the biggest problems in starting synthetic fuels is getting someone to take the big step; everyone seems to be waiting for somebody else. The fact that 75% of Western shale oil belongs to the Government is a problem. The Government sits on it and doesn't know what to do with it. Regulations and changes in regulations continue to hamper synthetic development.

There is really no master plan to develop Western shale oil to its limitation, be it 2MMBPD or 8MMBPD. It's a hodgepodge, with industry moving out now on some loan guarantees. We have the largest resource of hydrocarbons in one place, much larger than in the Mideast, and it's not being developed systematically. DOE is trying to push, but other parts of the Government are regulating and pushing up costs. Costs appear to be competitive now and there seems to be considerable concern in OPEC for what might happen; a petroleum glut might be contrived to cool the synthetic enthusiasm in the US.

Coal liquids may find their way into refineries. We don't know how we might handle their higher aromatics; we don't even know if we could operate continually at the limits of today's specs.

Wayne Berman,CSIS- To Dr. Lander: Do you think it possible to develop a national plan for developing shale oil? Aren't there too many contentious political forces? Is it possible?

Lander- Possible, but not easy. Perhaps analogous to the TVA. Not likely under the Reagan administration, or any other, now. It will take ten or fifteen years before it will get the support. Private operations and the two federal leases are moving ahead and may prime the pump. The potential for synthetic fuel development in the US may be an important lever against imported crude; not that the quantity effect would be large, but that the potential and the psychology would be important.

Poritzky, FAA- I thought I heard that cryogenic fuels might be competitive around the turn of the century but that Mr. Momenthy and Dr. Shank said that isn't likely. Is there any feeling on this?

Brewer- We think there are developments on the horizon that can drastically

reduce the cost of hydrogen. On the charts Charlie showed, the price is expensive. But in the proposal he mentioned for delivering hydrogen to LAX, we participated in that and the price was around $7 per million Btus, taking credit for the electricity and by-products. In addition to the $7, there is another $1.50 to maintain liquefaction at the airport and to keep it continuously supplied to aircraft. This is extremely competitive and is based on rather conservative assumptions. There are other developments coming along, such as magnetic refrigeration, which may further reduce costs. It is presently in the lab scale at Los Alamos, essentially in the curiosity scale but, if successful, might cut liquefaction costs by as much as 40%.

Hydrogen should be attractive to aviation at some time in the future; we do not say it will be within the next ten years or when it will be, but the potential is there.

Blake- I may have gotten across several things 180 degrees from intended. Personally, I believe that petroleum will be around for at least twenty or thirty more years at competitive prices, unless something drastic happens to the entire market. Changes may come from an unexpected direction, such as the proposal to supply LH2 to LAX. I believe the important thing is that changes may come rapidly and unexpectedly from a variety of directions, not just technological or economic. Keep in mind the 15-year visibility limit. We certainly shouldn't support every avenue equally, but it may be a mistake to rub out or ignore any completely.

Borger- The logistic problem for LH2 is considerably larger than LAX or O'Hare. An LH2 airplane is a whole new airplane; the least that will be changed is the engine. (several responses, "That's right").

Blake- One of the things that comes out of the study is that future capital costs will be high, even staying with petroleum. So when you are facing almost immeasurable capital costs, you should compare them with other almost immeasurable costs. It is difficult to guess how we might come out on some of these things in the long run; we may not be able to forecast with confidence on any of them for more than about five years right now.

Momenthy- A comment on the greenhouse effect. If you're talking about hydrogen from coal, considering the first and second laws of thermodynamics, CO2 production is greater than with the production of jet fuel or anything else from either shale or coal. Conversion for the O'Hare demand alone, if done by electrolysis, would take a 6.5-gigawatt nuclear powerplant. It is not likely to be regarded as benign by the neighborhood.

Garretson, Mobil- On the NPC statement that refinery capability will be able to produce all product slate demands in any of the disruption scenarios: That may have been true in the past and may be now. But looking into the future with more middle distillate demand, especially diesel, with more small refineries shutting down and the other trends in the refining industry, there may be some need for an emergency jet fuel specification. It would be helpful to develop that now rather than when an emergency arises.

Blake- One of the things that might be looked at is what would happen to existing engines and aircraft if operated on a broader-cut fuel.

Garretson- More naphtha would not affect performance and that would come out of the gasoline stock, which might stand a reduction better than aviation during a disruption.

Afternoon Program

S. V. Drum, General Manager, Aviation, Chevron, U.S.A.(Standard Oil of California)- I'll be talking from the marketing view of my favorite subject, jet fuel. My company has not projected beyond the year 2000; as the discussion suggested here this morning, we conclude that petroleum-based kerosine will carry us through to that date. It's a novelty to talk about availability because in times of plentiful supply, like now, most of the people who talk to us only want to discuss price.

We conclude that kerosine jet fuel demand is likely to have very little growth in the period to 2000. We forecast a maximum growth of 1% per year from now to the year 2000, and I think this is as pessimistic a forecast as I've seen. As Charlie showed on a chart this morning, this will be far less growth than we have experienced in the past. During the 50s and 60s it wasn't unusual for us to have 15-20% growth per year.

Again as we've seen, motor gasoline demand is expected to take a precipitous decrease. By 2000, we expect the nation to be using about one-third less gasoline as it is today. On the other hand, distillate demand is expected to be 17% greater, including both kerosine-based jet fuel and diesel. The net result of these changes in light-product demands will be an average reduction of crude runs in the US of perhaps 1/2 to 1% per year. With crude runs decreasing and distillate demands increasing, the logical conclusion might be that the country will have difficulty meeting distillate demands. Chevron forecasts that distillate percent of run will rise from 29% in 1980 to 39% in year 2000, a spectacular increase.

As crude runs decrease, the feedstock will become heavier, as has been pointed out; producer countries will force that upon us. As they do become heavier, straight-run light-product yields will decrease proportionally, further adding to our supply problem. Light-product yields can be improved significantly by refinery conversion units which use cracking and hydrogenation. We are heavily involved in both of those. These conversion units require substantial investment and do increase operating expense. Most major refiners either have or are making these investments.

As a case example, our Pascagoula, Mississippi refinery, considered to be one of the most modern in the industry, is undergoing a billion dollar resid reduction retrofit. When this is completed, mid-distillate yields from Arab heavy will be more than double that from a topping refinery of the same size.

The real imponderable is the question of crude availability; this worries all the planners in the oil companies almost every day. Chevron is forecasting that large volumes of oil will be found and produced in the US, but about 50% of our oil needs will still be imported for the next twenty years from relatively insecure foreign sources. Although progress is being made, unfortunately synthetics and energy from other sources will not be available in sufficient quantities before year 2000 to render us independent from these insecure foreign supplies. We are enthusiastic about synthetics long term

and, as we saw, with proper hydrotreating, they are a proper source for high jet fuel yields. Chevron has a large commitment to shale, as was shown this morning.

We receive endless questions of whether broadened jet specifications would result in increased availability and decreased price. We may differ from some of the other views you will hear here, but it is our conclusion that broadening the specifications within the mid-distillate range will not necessarily result in a substantial increase in the supply. When supplies of distillate are long, as they are today, noone is having any problem getting the jet fuel they need. When times are tight, aviation will get about its share, along with the diesel customers and the 2-oil customers. If we broaden the specs for jet fuel, we would reduce the production of the components for these other customers, for which there is an increasing demand.

One change that could increase availability would be a relaxation of flash point, due to the decreasing demand for motor gasoline. In times of plenty, this could have an impact (downward) on price. When the industry is long on alkylate, the price of JP-4 has reflected that. Also when alkylate has been tight. I believe the same would hold in going to a lighter-product jet fuel encompassing some of the gasoline which is now going to become surplus. It could have an influence on price in times of plenty.

Our calculations are about like everyone else's: a ten degree Fahrenheit reduction in flash point from 100 to 90 degrees would permit an additional 1% of crude to be included in jet production, which could amount to about 10% of the total future jet fuel supply.

In conclusion, how will these shifts in light-product demands affect jet fuel? There will be an increasing competition for products in the mid-distillate kerojet range. It is reasonable to conclude that through the rest of the century, the availability of kerojet will be dependent on the industry's ability to meet distillate demand. Reduced quality crude oil will not produce enough straight-run fractions to meet the middle-distillate demands. Additional resid conversions and hydrocracking will be required to convert heavier fractions to distillate products. This will require sizeable investments and higher operating costs; both will have to be reflected in price.

We think the greatest uncertainty in availability of jet fuel relates to crude oil supply. However, if domestic crude oil is found in the volumes that are currently being forecast, and if foreign imports continue to be available, and if the political climate permits reasonable return on investment, Chevron believes that the oil industry certainly can meet the aviation industry's demand for jet fuel through the year 2000.

Q- I've heard that you've been delayed on your refinery modifications at Richmond by local environmental regulations.

Drum- That's true, Al, but that modification was pretty much involved with a lube oil plant; it really had nothing to do with enhancement of jet fuel capacity.

Dr. Theodore R. Eck, Chief Economist, Standard Oil Company of Indiana (AMOCO)-

Looking at the world oil demand, it is expected to go up very slowly in comparison with experience. There is absolutely no question about oil availability at least through the balance of this century, and we do forecast beyond the year 2000. We're up to 2020 now and still have lots of oil. There's no geologic restraint on oil production as long as any of your airplanes will fly.

We're indicating a big growth in the use of gas. That's a new dimension in hydrocarbons; the use of methane gas. A lot of coal use, also. We think the prices are going to be structured about as you see here; oil is and will remain the most expensive fuel. Natural gas is going to be cheaper than oil in all of our major markets of the world. It is not a premium fuel; it has less "place utility", as we say in Economics; a cheaper fuel. And coal, of course, being the least mobile and least flexible, carries the lowest price.

Our next point is that most energy growth will come from non-petroleum sources, say in 1991. Most of our oil will come from non-OPEC sources, indicating no pressure from OPEC supplies. I indicated that there will be a great deal of gas available in the world and I show here some countries that have large volumes of gas available for export. We could show several slides of countries that have commercial quantities of natural gas for sale. There's no question that there's more gas available in the world than there is market. The question is who's willing to pay the market price for gas, and I'm assuming the price will be competitive with the price of residual fuel oil in the end-use market. This suggests that natural gas , FOB, will need to be priced considerably cheaper than crude oil.

Who are the countries willing to accept these low prices, not necessarily all you see here. But certainly the USSR will have to because of limited capacity to export oil. This is the general rule, that the big exporters of natural gas will be the ones that do not have exportable surplus volumes of oil. So you are going to be seeing gas exports from countries you do not normally associate with the international petroleum business, such as Thailand, for example, Qatar, several emirates, Tunisia, and so on. Incidentally, Mexico has immensely large volumes of gas, much of which is associated with oil and will either be reinjected, or they will have to find a market for it.

We think the Soviet Union will have some exportable oil, but not much. Oil production will keep up with consumption in the entire bloc. The Soviets will therefore be increasingly dependent on gas for the foreign exchange they desperately need to pay for imports of material and foodstuffs. We see the USSR continuing to supply considerable amounts of natural gas to western Europe.

We think there is an immense amount of material still to be found in the US, OPEC and especially in the Free World. When you see what's happening with exploration activity, there's a tremendous increase in activity outside of OPEC overseas. We're starting to get some major discoveries, some of which have and some of which have not been announced. We're developing some new major discoveries, much of which is gas. We continue to discover more hydrocarbons overseas than we're producing and the production line is flattening out. We think in the future that discoveries will exceed or at least match production, so there is no indication of a supply restraint for geologic reasons. Our forecast shows the world oil production increasing

steadily out through the end of this century; we do not concur with the forecasts that expect world oil production to peak in the 1990s. We view that peak as well after 2000.

Looking at demands on OPEC, there are no particular pressures in meeting these requirements. Note that Saudi Arabia stays in a very comfortable range of 6-7 MMBD. We see Iran and Iraq coming back into production. The total demands on OPEC are in the max range of 25 MMBD; OPEC has already demonstrated its capability of delivering well over thirty. WE envision a substantial production capability surplus in OPEC as far as we can forecast, or a world surplus production capability in the 8-10 MMBD range for the next twenty years. That isn't meant to say that the world will be swimming in oil; this is excess in the sense that it isn't going to be produced. But the capability of increasing production exists and will represent some sort of discipline on world oil prices. That's particularly true in that more than half of that surplus is in Saudi Arabia and they have the capacity to maintain that share into effective infinity, due to their immense resource base.

OPEC will not remain a cartel so much as a continuing single, firm, oligopoly, dominated by the production and pricing policies of Saudi Arabia. You probably saw the announcement this morning that OPEC is going to meet again at the end of this month. We expect it will be clear at the end of this month that Saudi Arabia is, indeed, in control of the structure and pricing of crude oil in the world. It should lead to a higher but unified price structure.

Underlying much of this optimism is the role of conservation, which I'm sure you have discussed. We look for it to continue, but we think we have seen a large percentage of it already. We continue to conserve, but we have done the easy steps and we think the situation in Europe is similar. We think world oil production will resume its upward rise and we think it will go up some next year. This explains in part the probability of OPEC's moving the price structure of oil upward.

We've had a good discussion on the future of the refining industry and our outlook is essentially the same. We'll be producing less middle distillates over the longer term, but we'll be producing more during the 1990s than we do today. The big thing that's happening is the big reduction in gasoline naphthas. I conclude from this that we have big troubles with kerosine. It will be continually short and will be more expensive to make than gasoline. A long time ago, that was the original situation in the petroleum business. We will make kerosine by hydrocracking, which will be very, very expensive; we do not have those facilities in place, so you are going to have to pay the price of the new refineries.

Another problem is that we will be losing the residual fuel market, which is where we've been able to dump materials we didn't like on the road to making kerosine. To throw out a number, kerosine could cost as much as 10% more than gasoline. One of the key questions is what happens to the quality of diesel fuel. The easiest way to improve cetane is to dump kerosine into diesel fuel.

To finish up my optimistic viewpoint of where the US petroleum industry is going: This is a great year; we're going to drill 77,000 wells, more than twice as many wells as we drilled four years ago. The number of oil wells

alone this year is up 43%, a tribute, of course to oil decontrol. The next decontrol option is natural gas, which should begin in 1982 and be accompanied by a big increase in drilling activity. I think it may be a more comfortable world than our Chevron friends are suggesting, because we see our importing only about 4 MMBD, or considerably less than half our requirements. We believe this will be accomplished by, first producing a considerable amount of natural gas, displacing much of our need for oil and second, we are just going to find more oil. Last year was a great year; we think we found as much in this country as we produced and you will notice that oil production is heading up, rather than down.

Ebinger- Ted, on your non-OPEC supply, what kind of rise do you see in non-OPEC demand to consume that supply, rather than having it available on the international market?

Eck- Incidentally, we think the proved oil reserves in Mexico are already bigger than in the US and that the potential reserves in Mexico are the order of twice that of the US, and Mexico is a non-OPEC country. Africa looks like a very generously-endowed continent, particularly for liquid hydrocarbons. The Far East is difficult to gage, but a lot of material there. I'm impressed with two events. One is the very high level of exploration going on now all around the world. In our own company, we're currently exploring in more than fifty countries and we're making major discoveries. As economists, I think we are guilty of underestimating the elasticity of both supply and demand. The world may balance even more quickly than we suggest.

Q- How does cost relate to drilling depth?

Eck- We are drilling deeper in the US and one reason is because of a sort of silly law that says that if you drill wells below 15,000 ft you can sell the gas for three times as much as if you drilled shallower than 15,000 ft. We're trying to explain to Congress right now that we don't think that's a very clever law. We can drill at least three times as many wells at 7,000 ft as the cost of one well at 15,000 ft. If we get the Government out of the well drilling business, I don't think there is any question that we'll be drilling more and cheaper wells.

It's also true that there is a lot of gas at deep elevations and that we're learning how to find it. Another exciting thing on the road to domestic self-sufficiency in the oil and gas business is new siesmic technology which permits us to look underneath an igneous overlay. That may not sound exciting to a non-geologist, but it opens up all sort of new land, particularly for gas. The deeper the formation, the better the chance for gas, rather than oil. Our estimate of the gas base is going up by leaps and bounds, partly from new knowledge about geology and partly because of the new big, big discoveries. Tuscaloosa deep gas, below 15,000 ft; very large gas pools. Whoever would have thought to look under the Rocky Mountains for gas? But there's just a hell of a lot there, all the way from Mexico to Alberta.

We're drilling more and more wells, but dry wells are not going up as a larger percent of the total effort, suggesting that our shooting average is better, something the economists might not have forecast.

Girard, USGS- I'm not sure I can share in your optimism of future supplies of

oil and gas, both domestically and world-wide. I agree with you in the amount of exploratory effort and I think this is surely a banner year. However, if you look at finding rates, especially in the US, it is a dramatically dwindling declining curve. I certainly agree with you that the percentage of dry wells is less today and that a lot of new wells and fields are coming in. But the supply is not really coming in to turn down the curve. In fact, the USGS just completed a study of all the offshore areas of the world, excluding the Soviet Union and China, and the same type of decline curve is apparent in all the offshore areas as in the Lower 48. To me, the evidence is overwhelming that the supply really is not there.

There is another problem. In order to meet consumption, you need to deliver the product at a particular rate. I think this country is well-endowed with resources and the resources are there world-wide. However, the field-size distribution of these resources, as well as for shale oil, geopressured zones, oil and gas from Eastern shale, does not allow them to be put on line and produced at the rate we need. It is more of a deliverability problem than it is a total resource problem. It's like draining an Olympic-sized swimming pool with a garden hose.

Eck- Everybody has different data and, fortunately, we have a lot of geologists, because we're looking in places now that some of our geologists didn't favor and we're making finds. We had been expecting to see in our own exploration efforts this decreasing productivity; we're not seeing it. We're continuing to hold about the same success per unit of effort. We don't think we are doing that much better than everybody else.

You can count your money in many ways and there are a lot more dimes in circulation than fifty-cent pieces. You find the big bills first, but there are still a hell of a lot of small ones left around. That has been our sort of experience. When we see the 1981 results, I think we're going to see maintained or increased the reserve/production ratios.

Oswald W. Girard, Jr., Deputy Chief for Oil and Gas Resources, U.S. Geological Survey- Our office is responsible for predicting a variety of resources, including oil and gas, coal, uranium, thorium and so forth. My own specialty is oil and gas. I brought with me slides only on domestic resources, not on the world-wide supply. We do this by considering all the categories in the McKelvey Box, and work on filling the undiscovered side. So the USGS stays away from the known side of the box. I'm only going to talk about conventional resources, not the unconventional or small resources. There's another whole category of unconventional sources that we're just getting into.

The Service looks at each individual basin in the US, both onshore and offshore and, by subjective Delphi approach, try to predict just how much resource lies under each of these basins. Through a Monte Carlo process, we aggregate these data and come up with a total for the entire United States. We report the resources in a log-normal distribution; we feel there is much error in the predictions, in fact, even in the known reserves. We feel we do justice to the system by predicting the probability distribution, T and N on 90% of the resources, that there is a 5% probability, one chance in twenty, that we will have that much. And then a 95% probability, or a 19-in-20 chance that we will have X amount. So you can choose any probability you want and

read off the amount of hydrocarbon that will be expected with that probability.

In virgin or undrilled areas, we try to use our best geologic judgment on the chances of hydrocarbons occurring. This is what we call our marginal probability or our basin risk. In this case, some of the North Atlantic where no finds have been made, it is 30%. So we're saying there is only a 70% chance of commercial hydrocarbons occurring to begin with. I may be presenting a pessimistic picture, but I believe the Service has been guilty of being too optimistic in the past.

What do the undiscovered resources look like? Basically, this is aggregating the various provinces and we show the low number of at least 95% probability of that amount and then the high number of having at least 5% probability of that amount. So, total offshore, going out to 2500 meters of water, beyond the current production capability, we have a distribution from about 42 BBbl of oil at the 95% probability level to 71 BBbl of oil at a one-out-of-twenty probability, or 5% chance. So there's at least a 95% probability of 42; it's going to be larger, and at least a 5% chance that there will be 71. We don't assess the tail end of that distribution, which goes way out.

For the total US, we see between 64 BBbl and 105 BBbl of oil yet to be discovered from conventional reservoirs, based on current economics and technology. For gas we see anywhere between 474 and 600 Tcf, total US. To see just how big or small these figures are, we have in the bank today about 58 BBbl of oil and 328 Tcf of gas. Throughout our long production history, about 150 years, we've only produced 121 BBbl of oil and 578 Tcf of gas. So that will give you an idea of where we've been in the last 120 to 150 years and where we are now. If you believe our numbers, we've already discovered between 60-75% of all of our conventional gas and only discovered between 55-66% of all our conventional oil. I don't like looking at rates, but at current consumption, our oil will last 11-18 years and the gas 24-37 years. That just gives a feel for the size of the numbers; it is a dangerous guessing game.

As has already been said, we see aviation kerosine-based fuel available until the year 2000. Some 26 to 40% of the production will come from offshore and 25-31% from onshore. My own analyses lead me to expect that anywhere from 45 to 70%, and 70% is a high number, of conventional production will come from federal lands. For gas, 43-55% will come from federal lands, heavily weighted to the offshore. All offshore, of course, is federal-controlled beyond the three-mile limit. Any way you cut it, there is an awful lot of regulation and constraint applied to production by the federal government.

All of Alaska north of the Brooks Range and all offshore Alaska is federally controlled, and we don't think there's much prospect onshore Alaska south of the Brooks Range. The way the feds play the game will determine how we produce the future supply. There is a little encouragement in Alaska because the Government is going to open up the old NPR-4, petroleum reserve. Under this administration we hope to speed up and streamline the offshore leasing process; they at least are trying to accelerate the exploration. We're trying to find out just what our national inventory is. Now we have nothing better than educated guesses.

We're now moving into the foreign areas trying to run inventories, for example in Venezuela, Nigeria, we're halfway through the Soviet Union, and we're doing Mexico and Indonesia. We want to put all of these into the same time and format so that we can compare foreign and domestic with Iran, Libya and so forth.

Ebinger- Have your studies concluded how much of our resource is likely to be on the unexplored federal lands?

Girard- Although it was mentioned this morning that only a small amount of federal land has been explored, experience has shown that the largest, richest fields tend to be found earliest and that we should not expect a direct ratio between the amount of land left to explore and the amount of oil expected to be found on it. On a large new area of land, such as Baltimore Canyon, there may be only a few structures that the oil companies think are worthy of exploration. It isn't fair to say that only two percent of the OCS land has been explored.

Q- How do you make forecasts on the Soviet Union?

Girard- We've had a couple of people in the Survey who have spent a fair amount of time in the USSR and one member who publishes an assessment of only the Soviet Union. The basis is going through all the literature available and talking to people, including a defector who works for Argonne Labs now. We also use geological analogies and the "lay of the land".

Q- Has Landsat helped with these surveys?

Girard- Landsat would have been a great help some years ago. Today, most of our interest is at greater depths, where little evidence will be seen at the surface. But we have a cooperative arrangement with China where there are large areas still unexplored and Landsat data gives the lay of the land where they can quickly drill to get the first assessments. Some people feel that Landsat is still useful in the US, but that is their opinion, not mine.

Dr. Joseph D. Parent, Consultant, Institute of Gas Technology-
Looking over some of the material that has been presented, basically I use the USGS data shown for oil in the United States. I try to evaluate everything I see published on oil and gas in the US and try to assemble an overall picture. This year the USGS stuck with the undiscovered gas and oil, while from the Potential Gas Committee, we also have the so-called probable and undiscovered, which they call possible and speculative.

My own evaluation of gas was to look at Harry Kent's (Potential Gas Committee) breakdown by sections of the country. In some cases USGS values are higher, while in most cases they are lower. I established a range for each section and came up with an overall range which is a little wider than USGS. The USGS uses a more sophisticated Monte Carlo method, while the Potential Gas Committee uses a consensus figure for each group, where groups need not be consistent with the others. The same type of thing is true about oil, gas and coal throughout the world, resolving the differences among numerous puublications. The most dependable ones are from The World Energy Conference, especially for coal.

The trend of oil and gas discoveries in Mexico has been interesting to me. Mexico produced oil before 1900 and it was the second-biggest producer in the world in 1920. Forecasters may note that when the well logs were re-examined from the Reforma Field and deeper drills were made, they came into hugh amounts of new oil and gas. These would never have been forecast on the basis of the finds at shallower depths. So there are always unforseen factors that seem to enter to affect these evaluations; the same things have happened in Hubbert's analyses. His analyses do not take into account the effects of price, taxation and this sort of thing. He has never seemed to be interested in those factors because he apparently considers them trivial in the overall picture. As far as I'm concerned, a projection which makes future production absolutely symmetrical with past production is unacceptable. In the early history of a process, you can probably fit any number of equations to the data and extrapolate them to almost any value you want.

Kurt H. Strauss, Senior Technologist, Research and Technical Department, Texaco, Inc.- Fuel flexibility means different things to different people. One approach is parametric testing and the other one is a drastic change in fuel specifications. My basic contention is that different refiners will react differently to different problems. They will have different crudes, use different processes; what we will see is a gradual change in fuel trends and we will not see a drastic fuel change in 1995, or at any other specific date. We don't have the same problem all over the US or all over the world at the same time. In addition to different crudes and refining capabilities, more important are different demands for the product slate. In many cases, that is what determines the quality of the aviation fuel.

A recent paper by Bob Friedman of NASA Cleveland shows that the amount of fuel which is approaching spec limits is increasing with time. That is the problem that we foresee, and how to attack it from a practical view. You do parametric testing, examine the problem over a range of variables, from good quality to the worst anticipatable. This might tell an airline there are times when it pays to trade engine life, not efficiency, but life for fuel cost. A test of the worst fuel should not be taken as a signal that this is what the future fuel will look like, but that is what's happening.

There is inertia in the basic system; we've heard today that the spec is fixed for the next twenty years. I think we'll see a continuing pressure by suppliers to relax here and there a little bit, followed by a scramble by everybody to see if this is a legitimate way to go. That is my main message today. We're looking for maximum flexibility in terms of constant minor changes. Incidentally, I don't see an increase in flash point as being in this category; I agree with Al Momenthy that today's aircraft are fully certificated to use that fuel.

We should caution against over-simplication of a highly complex problem. Somebody has said that it's too complex to be solved by the application of simple logic.

William G. Dukek, Senior Research Associate, Exxon Research and Engineering Co.- First, I'd like to tell you a little bit about the capital requirements of the refining industry in the US and, second, to tell you about our attempts to zero in on the quantity and costs of jet fuel.

US refiners are facing some unprecedented uncertainties during the next twenty years. They are, of course, concerned with the mix and quality of product demands, the availability of raw materials, including synthetics as they become available, and important external factors such as car design and government regulations. We've had to drastically revise our demand forecasts downward because, since 1973, we've seen interruptions in crude and a ten-fold increase in price. The effect, as you know, has been to reduce the refinery rate in this country to less than 70% of capacity. In fact, some forty to fifty refineries, mostly small ones that lack conversion capacity, have been shut down; there has been a loss of about a million BPD of capacity in the US. Present projections, contrary to pre-1973 optimism, are for about level demand.

The expected decrease in motor gasoline demand will be accompanied by an increase in middle-distillate demand, specifically jet and diesel fuels, which will essentially double by 2000. This shift will require refiners to convert their naphtha production to middle-distillate production and use more efficient hydro-treating catalysts.

The fastest growing market is expected to be automobile diesels, where proposed regulations on particulate emissions will be especially difficult to satisfy. This chart shows that only two of the three engines tested would meet the 1982 regulations on particulates. None of them meet the proposed 1985 regulations of 0.02 grams/mile. This chart of particulates against fuel quality shows that even for jet fuel as low as 16% aromatics, only the smallest engine, like a VW Rabbit, will meet the 1985 standards. This is a major problem which will require cooperative efforts of both the petroleum and the automobile industries. It impacts directly on jet fuel availability.

You've heard that crudes are becoming heavier. The average crude mix in the 1980s, with an API gravity of, say 32o, would yield about 19% heavy fuel at a refinery that lacks bottoms-conversion facilities. Now from a heavy crude, with say 28o API, we end up with an enormous 40%. But the market, even in 1985, is only going to require about 9% heavy fuel. Today there is about 1.2 million barrels of bottoms-conversion capacity in place. So we're going to need another 700,000 bbl capacity in the next few years.

The choices among these processes are really quite difficult, such as: vis-breaking, three or four kinds of coking processes, residual hydro-conversion processes, so that it depends much on the market for byproducts such as coke, fuel, gas or asphalt. Refiners are faced with capital investments of about $50 billion in the next ten years. Of this, about 15% must be directed at a bottoms-conversion type program.

On this chart you can hardly see the contribution from synthetics, shale and coal, by the year 2000. Projections vary considerably, from one to five million BPD. They will have a significant effect on refining because these materials contain nitrogen and oxygen, and are quite deficient in hydrogen. Since shale oils are paraffinic, they are ideally suited for middle distillates. Coal is different, with the option to produce either liquids or gas; the latter route could be the key to the new automotive fuel, namely methanol.

Looking into the future, all the refiner sees are questions: The extent of

automotive diesel; meeting particulate emissions; the kind of residual-conversion process to install; how to deal with these heavy, high-sulfur crudes; the future octane requirements; the amount of synthetic in his feedstock; can he count on the product demand mix; what does he do with spare capacity, shut down complete units or shut down the complete refinery; what role do oxygenates play; and should he be investing in methanol? Then in the nitty-gritty: what kind of engines will Detroit produce; will the Government make the problems worse or easier and, finally, where in the world is the money going to come from for these investments?

Turning from the refiner's problem, let's go to the cost and availability of jet fuel. NASA is making a serious attempt to home in on the cost and availability of future jet fuel, largely to determine the needs for future R&D. NASA has let two 24-month contracts for computer studies; one to EXXON Research a year ago and the other to ICF a few months ago. These will look at refinery yields, energy and costs. Look at US and NATO jet fuel possibilities to optimize refinery yields, costs and energy consumption out to 2010, the eastern and western regions of the US and Canada, northern and southern Europe. A mix of refineries is considered: simple, intermediate and complex, while crude sources considered will also include synthetics.

The approach in both contracts is to use programs that are generally employed in industry refinery-planning studies, looking to Pads I-IV as a group, because of all the inter-transfer that occurs, and Pad V, the West Coast, separately. We develop models for individual refineries and then integrate, using all the processes and types. We take qualities and quantities out of the crude data bank, the best information on synthetic quality, and then vary the demand for gasoline, distillates and heavy fuel products during the time period.

The model outputs include yield, investment, operating cost, and return on investment. One of the most important efforts is to try to verify the results against historical data. Finally, you run parametric variations in which you examine Jet A boiling range and quality against the model and produce an output in terms of incremental costs of Jet A, with different quality variations. One of those variables could be aromatics, as has been illustrated today. Costs will be in terms of 1980 dollars.
Finally, we may develop costs for processes which are still in the pilot stage.

As far as the Exxon project is concerned, we have about a year to go. The refinery process models are completed, as have the crude quality forecasts, as well as product demands. We've defined the jet fuel quality variations for the parametric study and all of the processes have been bridged to our linear-programming systems for the least-cost, least-energy and other optimization steps.

Q- The naphtha fractions available from the excess motor gas, which many people are predicting, can be used to increase the aviation pool in the wide-cut direction. But this carries the stygma of moving in a less safe direction. What's wrong with combining the diesel and the motor gas pools so that diesel moves toward the wide-cut direction? Certainly the naphtha is valuable; it's got to be used; you can't throw it away.

Dukek- There are state laws governing sale of diesel fuels, as far as flash

point is concerned. This is not the same for aviation fuel. So we are more limited in wide-cut diesel fuel and which end we can operate on; we can only raise the final boiling point. That's being looked at now; to handle more cetane and heavier-type diesel fuel.

Q- There may be many ways of solving those problems, not the least of which is to change the laws. Or blend the naphtha and diesel on location, as they are used; don't ship them and dispense them as a combined product. Seems to me the diesel question is being used to alarm the aviation people that diesel cars are going to steal all their fuel. Here's this big pool of motor gas which has always been the sacred cow in the US and now we don't know what to do with it. It will work in aircraft, but it will also work in diesels or in stationary powerplants. Furthermore, it doesn't have to be reformed in order to get octane. Can't diesel go down to 100o flash?

Dukek- This may be one of the more insoluable distributional/logistic problems, either blending on site or changing the laws of fifty states.

Q- Maybe diesel and jet fuels both have to change.

Q- I'd like some comment from industry on where these capital funds will be coming from and whether you think they are real, whether government spending or other sectors of the economy will have claims on these same funds.

Dukek- Fortunately, the petroleum industry generates capital much faster than the aviation industry does at the moment. We obviously have many alternatives for investing that capital. There is no question that the investment for refinery modernization will be found because that comes first. But some of the smaller refiners won't find the capital. That impacts on jet fuel because it will affect the price of all products.

Q- There has been some legislation which almost gets into the punitive category, for example reduction in the depletion allowance. If you build a reformer to use some of this naphtha you are otherwise stuck with, you are not allowed to write it off under any reasonable depreciation plan. The same appears to building other refinery modifications to use the other fractions that you otherwise can't handle. Am I wrong about that?

Dukek- I think the scheduled depreciation rates are spelled out by law.

Q- You have to invest so that almost any refinery can handle almost any types of feedstocks, irrespective of whatever products you might make. Right?

Dukek- Right. I don't think I can answer the specifics of your question. I know there planned changes in the law which should help on the depreciation you mention, for our other industry as well as for others. But I can't answer your question.

<u>Albert. M. Momenthy, Manager, Transportation Energy Programs, Preliminary Design, Boeing Commercial Airplane Company</u>- Steve Drum stole my conclusions and John Borger, my straight man, left. Kurt Strauss and Bill Dukek haven't given me the usual rough time, but maybe I can still stimulate some discussion.

We've had an aviation fuels program at Boeing for eight years now. Unlike rumors people have heard, it is not just computer modeling, which is only about 15% of the work. It is highly involved in economics of the aviation industry, and of the petroleum industry. It's sometimes termed the Boeing interference in the oil companies. We got into this because fuel once cost only 12 cents per gallon and was 21% of the direct operating costs of a 727. Even we believe those days are gone forever. Currently at about a dollar a gallon, fuel comprises about 45% the DOC of a 747. What Boeing is trying to do and what the industry must have is at least a holding of the line of that share of the DOC.

The petroleum industry knows how to make a profit and this means no unsold product from the refineries. A refinery with residual being sold below cost, makes up the difference from gasoline, jet fuel, and other products. So after we spent two years doing cost and delta-cost studies on jet fuel, we decided they didn't make too much difference.

We feel very strongly that the aviation industry is going to grow and so we have been looking at options for future fuel. In 1980 jet fuel was 5.2% of the refinery output, supplied by approximately 15% of the refineries, accounting for about 31% of their output. Individual refinery Jet A yield was up to 25%. There is a big difference between "marketed" and the refinery capability. Our 1995 forecast shows about 8% of the US refinery output could be Jet A. We have made a comparable study on international fuel. If this were to be supplied by the 15% of refineries currently supplying jet fuel, distribution and other considerations would mean that individual refinery output of jet fuel would have to go as high as 40%. We don't believe the security of the market or the profit associated with jet fuel would allow a refiner to dedicate 40% of his capability to the jet fuel market, regardless of what the specifications were.

In the long run we see jet fuel coming from shale or coal, emphasizing that this won't happen overnight. The NASA Lewis study which has been showing deterioration in jet fuel, unfortunately, does not include the latest data.

We have analyzed a large number of refineries in the US under various conditions, optimizing for jet fuel and for diesel. A desirable level of jet fuel production is between 15-25% of refinery output. Some refineries now fall below 15%, but a lot of them would like to get their market share higher. We agree that the jet yield should increase by raising the freezing point; however, we feel we would not get that fraction. Unless someone came up with a significant price break, not cost break, we don't see any attraction for raising the freeze point.

Lowering the flash point has a lot less impact on the aviation industry. The heat of combustion goes up and aromatics would typically go down. However, we don't think we would get more or cheaper fuel. Before we worry about changing the flash point specification, someone should worry about getting deliveries down to where the spec is today, allowing the delivery of 100o flash point jet fuel.

We couldn't develop a scenario that would push the aromatic content above 25 volume percent. We can always point to a few refineries which reach up there, but they are isolated cases. We would never want to base the aircraft

industry on a few isolated cases. Aromatic levels on the West Coast have now leveled out and have decreased. If we had believed earlier predictions we wouldn't be able to compete with the A-300 today.

Any fuel study must consider product distribution. By the way, UOP announced in Canada week before last that they have booked orders for 8 million barrels worth of bottoms-upgrading equipment over the next eight years. We took these projections and some of our own to see what the refinery of the future might look like, with the residual market receding and disappearing. We see no way for the refiners catching up with the decreasing quality of the crude between 1980 and 1990. Refiners are going to have an excess of residual until 1990. They will probably have to sell their residual at a lower price per Btu than the cost of the crude and smear that cost up through the gasoline and middle distillates.

We think the refiners that survive in 1990 are going to have the capability of putting out zero residuals. During the 1978 crisis and even today, the refineries that are making the most profit are the sophisticated plants with the most flexibility, even though their overall thermal efficiency may be lower. They are undercutting the price of jet fuel from the so-called simpler refineries; they can meet the demand for product mix more closely.

The Big Four are doing quite well; they have 70% of the market. But that has come down in two years from 72% and we see it dropping to 68%. Before decontrol, we identified 46 refineries producing jet fuel; producing, not selling. There are currently 51+ refiners marketing Jet A. We put the + in because there are more like 62, but we feel some of them won't survive the market; they are too small to compete in the up-grading. Some, like Citgo, are doubling their capacity for jet output.

With due respect to Exxon, we don't think the tremendous investment in the Donor Solvent Process is attractive because of the high-aromatic output to compete in a declining automotive market. We feel the most successful private processes will be the synthesis processes, somewhat like SASOL and Mobil M; they are the most likely for near term high-quality fuels, like diesel and jet. One refiner told us that if we would design airplanes to accept a higher aromatic content, with direct-hydrogenation coal liquids, we could save 9% of the energy in US refineries. If you did that, it would drop the heat of combustion from 18,400 down to 17,400 Btu per pound. That alone, without accounting for our guarantees on range/payload, would cut that 9% in half.

We are spending a lot of money to save fuel consumption in new aircraft. We would hate to see that reversed by a change in fuel properties.

We tried to develop the most optimistic scenario for synthetics and conclude there is no way, combining coal, oil shale, oil sands, or whatever, worldwide, that we could develop more than 9% oil liquids by the year 2000. That is the absolute maximum. The 5% or so we saw from Chevron, we consider more reasonable.

In summary, we feel increasing jet fuel demand will be met by more refiners entering the jet fuel market. Ultimate development of oil shale and coal. We don't see jet spec changes significantly improving jet availability or price.

Q- How much fuel can we save by flying at slower speed? Is it significant?

Momentny- It's significant, but I can't give you the number. Mr. Borger, who was here but left, could have given it to three places. That information is readily available and I can get it for you.

Blake- I had a chart this morning on DC-10s which showed that after you cut down to about Mach 0.8, you actually begin to lose fuel efficiency by going to lower speeds. In other words, those airplanes are designed to cruise at fairly high speeds. If you start getting up on the drag rise, the fuel consumption goes up rapidly. On the chart I showed for effect of headwind, the first time I saw the chart I thought it should go the opposite way, because the seat-miles per pound of fuel decreased as speed decreased. But the curve was correct. The airlines have already taken the optimum they can on speed reduction; there's really no reserve left.

The turboprop shown in the Lockheed data is more fuel-efficient, although that airplane is designed for optimum fuel efficiency at Mach 0.85. However, that airplane was designed for an arbitrary requirement and a more fuel-efficient turboprop would be designed to operate around Mach 0.7. It would be a completely different airplane.

Momenthy- I think that turboprop data is up for question at the 0.84 Mach number, Charlie.

Blake- Well, that's true. We don't have the prop yet or the gearbox to go with it. More important, the industry will have to pay for designing and certificating the new aircraft, but they can't afford to build the broad R&D base that will justify their proceeding toward these new fuel savings. Lockheed, at least, says it is completely dependent on a continuing, or even an intensified NASA program in aeronautics, in order to meet the Aerospace Industrie competition for the Delta Airline 150-passenger "1986 airplane".

Momenthy- Nor do we have data on the installation losses associated with the turboprops in these aircraft.

Blake- Right.

G. Daniel Brewer, Manager, Hydrogen Programs, Lockheed-California Co.- I have a few comments about the material Charlie presented this morning, using some charts on hydrogen as an aircraft fuel. If an airplane is designed to use hydrogen, it will have a smaller wing, a larger fuselage and a reduced gross weight. Because of the lower gross weight, it will have smaller engines and the engine noise will be less. If it's an SST you would expect it to have lower sonic boom overpressures, again because of the lighter weight and the smaller wingspan. The pollution advantage has been mentioned.

Energy, costs and safety are the three points I want to address primarily. Availability is an obvious advantage because hydrogen can be made from water, using just about any energy source. It has been mentioned and seems to be a popular misconception that hydrogen is good only for large airplanes. This chart shows it is indeed desirable for large airplanes, up to 5,000 nautical miles radius, over 10,000 miles out and back without refueling. But aircraft down to the size of a DC-9 or 737 would have about a 12% total resource energy

advantage. Its gross weight would be about 6% lighter.

Hydrogen costs are also much maligned. These costs came from a NASA study and are the basis of the costs Charlie used this morning. Here we compare aircraft that are designed to use synjet, liquid methane, and liquid hydrogen. LH2 costs $11 per million Btu, compared to about $8.47 for synjet made from coal. The direct operating costs are essentially the same, within the accuracy of the estimates. The estimate for synjet made from shale is a Boeing figure, I believe, and is around $6 per MMBtu.

As we discussed a little bit this morning, LH2 was offered for delivery to LAX for about $8.50/MMBtu, delivered into the aircraft tanks. That includes shipping coal from Montana, gasifying the coal at Barstow, California by the IGT continuous steam-iron process, which generates lots of spent producer gas, used to drive generators and produce electricity. The electricity could be sold and, as mentioned earlier, the price was agreed to by the California Public Utility Commission. Utilities are required by law to buy electricity at the rate prevailing in their district.

The base cost in the proposal was 7.145 cents per KWhr. Taking advantage of this price, the cost of the hydrogen is driven down. The base cost of electricity around the country varies from about 4 cents to 11 cents per KWhr.

With hydrogen at $8.50/MMBtu, aircraft can be operated at a very substantial direct operating cost advantage over synjet.

This lower curve shows the advantage of achieving laminar flow control over certain portions of the airplane by cryogenic wall cooling. This potentiality has been known for forty or fifty years, but has not been investigated thoroughly. These drag reductions drop the DOC to about 1.45 cents/SM, even with the $11 per MMBtu cost for hydrogen. Combined with $8.50 hydrogen, it is naturally very attractive. These costs do not include the other possibility I mentioned this morning, of doing the liquefaction by magnetic refrigeration. That process is probably even farther away from application, but all the tests that have been run on it indicate that it is a real potential. John Barkley at Los Alamos has demonstrated the capability of cooling liquid down to liquid helium temperatures, not just to LH2.

The main point is that LH2 is not necessarily a high-cost option. It does represent one that could be near at hand and competitive.

My principal topic is international interest in Hydrogen. This chart shows agencies and activities that are current. In Stuttgart, Germany, Sept. 1979, there was a meeting on Hydrogen in Air Transportation. Briefly, it was attended by fourteen nations and about 125 people were there. They represented airframe and engine manufacturers, airport operators, fuel producers, airlines, government agencies, universities and research organizations. It was a four-day conference, with a great deal of interest and an ad hoc executive group was formed, currently chaired by Willis Hawkins.

The group has been very active since in drawing up an R&D program needed to develop the technologies required by hydrogen-fueled aircraft. It shows the

long lead-times that would be necessary to switch to LH2 if that avenue is found to be economical. The group most recently met in Montreal in the first week in October, just past. There are nine countries represented on the AHEG (Ad Hoc Executive Group), who gave reports at the meeting. Some countries have one representative, some as many as three. IATA has been given a copy of the research program proposed by the AHEG and has endorsed it, the chairman of their Technology Committee, Dr. Richard Shaw, formerly of Qantas. They recommend that the program go forward, with the exception of the portion on engine technology, which they feel is not a vital issue.

Canada has a large year-long study sponsored by a seven-member-of-Parliament committee, recommending that Canada embark on a $1 billion hydrogen development program over the next five years. This is intended as a first step in a process to bring up hydrogen as a principal fuel in Canada, in spite of the fact that Canada is unusually well-supplied with hydrocarbon resources. The International Energy Agency (IEA) has agreed to accept a portion of the AHEG's program plan as an annex to their on-going hydrogen program or to accept the entire plan. The only reluctance is that the IEA mission now is not directed toward the use of hydrogen, only toward its production. They are investigating revising their charter to include use.

The European Economic Commission (EEC) has recently sponsored a study by Rolls Royce on hydrogen engine aircraft technology, starting from scratch design. Charlie has already mentioned that there has been interest from the Soviet bloc on our hydrogen aircraft activity.

We do not expect hydrogen to be accepted immediately as the answer to the world's aviation fuel problems. On the other hand, we see realistically that at least a couple of decades are going to be required for the technology effort, followed by flight demonstrations to convince airlines, the traveling public as well as the industry that hydrogen-fueled aircraft are safe and tractable. Another eight years will be required for development of the aircraft and the production facilities at key airports. We focus on the international applications because of the international need for a common fuel. We think hydrogen could start coming into the market about 1995.

We recently finished a study comparing the crash-fire safety of aircraft fueled with Jet A, liquid methane and liquid hydrogen, done for NASA Lewis. We concluded the cryogenic airplanes would be less susceptible to damage because of the location of the fuel tanks in the fuselage, exposing less frontal area in a crash. Fuel tank rupture is less probable because of the tank strength. The fuel causes least hazard to the surroundings in the event of a crash.

Momenthy- Boeing's position on hydrogen is pretty well known. We wonder how Dan solves the problems associated with loading and minimum ullage in the tank, particularly in short-range aircraft. It's a problem the space program has wrestled with, showing that with small aircraft and the insulation of the NASA report, you are stuck with at least 20% ullage. How do you get the fuel to the engines; where are the costs of the pumps? I don't know any way, without supercooling, how you can load a lightly-insulated cryogenic tank to within 2% ullage. It is basic thermodynamics, not a design problem. We spent as much money on how you get the fuel to the engines as was probably spent on the entire NASA program and, frankly, we were unable to come up with a

solution.
A pump that could meet the design conditions has a life of around a thousand seconds. What has been done on the cost numbers since the NASA program?

Brewer- It may be worth noting that the work on our pumps was done by both The Garrett Corporation and by Rocketdyne, two companies that have extensive experience in the space program. We have a lot of confidence in the work they have done on the thermodynamic components.

Momentay- Garrett and Rocketdyne are where we are getting some of our conclusions. Are any of your data based on studies since the NASA program, which NASA said was preliminary?

Brewer- Yes, the AHEG program is based on doing all the R&D technology which is recognized as necessary, including a lot of pump work.

Siegbert B. Poritzky, Director, Office of Systems Engineering Management, Federal Aviation Administration- A Boeing brochure made available to us today describes an airplane as a device which turns fuel into revenue; I think some of the users of the airspace would say that the air traffic control system can be considered a machine which turns revenue into delay costs.

Fuel used by the US aviation community is not a large component, about the same numbers as you heard earlier today. You've also seen that fuel costs dominate DOCs. Fuel impact is very high, indeed, and fuel saving pays off for air carriers, as well as for general aviation users. The cost of fuel has caused us to bring close attention to system delay, delay costs, and back to fuel costs and fuel wastage. This curve showing delay rising as demand approaches capacity, is a real-life curve; this one happens to be Chicago O'Hare airport, but numbers are similar for Los Angeles, Kennedy, and for enroute air traffic control sectors. It shows that when demand approaches some 80-85% of the design capacity of an airport, an airport complex or a runway, delay rises very rapidly. Therefore delay costs and therefore fuel costs also rise very rapidly.

This chart shows the problem in a different way: an airplane that wants to cruise at 33,000 ft and is forced to cruise at 37,000, spends 7% more fuel. If he has to fly at 17,000, 36% more fuel. That gives an idea of the kind of costs we are talking about.

There is significantly more traffic during peak hours than can be handled without delays. FAA established a Central Flow Control facility in 1968, which is essentially advisory in character and, in effect, manages the large flows of aircraft across the US, primarily transcontinental. FAA uses Fuel Advisory Departure Procedures, which is a fancy way of saying it holds aircraft on the ground until space is available. The system has severe limitations because the weather is not known ahead for the five hours needed. Another process is known as Quota Flow, a part of Flow Control, which limits the number of aircraft on certain routes. There is enroute metering implementation now at 20 of the centers that serve 18 of the major terminals. That is a process that keeps airplanes high, rather than having them milling around at low altitudes.

We have a chart of all the fuel savings that a 727 can achieve by installing

AD-A122 825 THE IMPACT OF PETROLEUM SYNTHETIC AND CRYOGENIC FUELS ON CIVIL AVIATION(U) FEDERAL AVIATION ADMINISTRATION WASHINGTON DC OFFICE OF SYSTE.. C L BLAKE JUN 82

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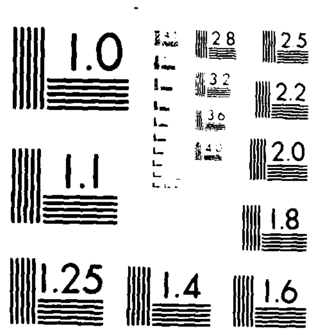

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

an energy management system, maintaining the airplane, polishing it up and so on; a six-minute hold at 6,000 ft wipes out more than all those savings on a 700-mile leg operation.

The programs I've discussed are restraining programs, managing the traffic by managing the demand and by interfering with what the airplane wants to do. A more recent process is Operation Free Flight, which shows that we can handle a certain number of flights on direct routes, rather than on the airways that have been established. But there is a limit to the number of airplanes a human controller can handle and manually juggle the variables, keeping them apart. He can handle more on pre-described routes than he can if they are on their own-designed routes. But even in the manual system today, there are a large number of aircraft that request clearance direct. He will often get that direct route.

Under the new administration we are looking at the entire ATC system for inefficiencies in the manual system. This could adjust sector sizes, corridors, all manner of fine tuning to let aircraft do more what they want to do. This project will go on for about three years.

Small savings are important here. Reducing the IFR, Instrument Flight Rules, average delay by one minute reduces direct operating costs by $250 million annually. That conclusion comes from task forces made up of airport operators, airlines, FAA and general aviation operators now at some twelve airports. These costs are because we are trying to put too many aircraft at the same time into a very limited airport resource. Discussed demand/capacity at Atlanta and other airports where demand/capacity is 143%. That happens because people want to travel at particular times. Equally important is the fact that there have been no new airports for some time, nor are there likely to be any new airports.

There is a lot of capacity that is not being used, but it is to places and at times when people don't want to go. There are few ways to increase capacity if we continue to have peaks in demand, with no new airports. We can improve existing airports with more runways, more taxiways and more optimal use of the airports themselves. That is a limited avenue. Reduced IFR separations is a relatively small gainer, something on the order of 5-10%. Segregated arrival streams and more arrival streams can appreciably reduce delays at some airports, Denver being an example.

What can we do about the manual limitations of the controller? One answer is advanced automation. The system has a fair amount of automation now, but none of the decision process is automatic. It's done by people, aided by radar, by good displays, by very automatic IFR-communication. But the process is totally manual, one at a time. If we are willing to pay for and use automation, the reductions in fuel penalties and the delays imposed on the users can be reduced quite dramatically. An automated system can accomodate user-preferred routes and profiles. The projection is about 6%, a quite ambitious number in the context we have been discussing. We have a simulation of such a system operating at McLean, Va.

It can deal with preferred routes and large airmass weather information. It will permit us to separate aircraft from aircraft, rather than separate aircraft from airspace, as is often done today. This a coming possibility,

but expensive. The present automation system has 1.2 million lines of code; the automated enroute system we are working on now would have 1.5 million lines of code in addition. Not a simple system.

We have a program under way for Integrated Flow Management, which takes the central flow function, automates it by providing better information to it, primarily in weather, winds aloft and weather fronts, with demand and with accurate knowledge of the capacity of the airport itself. At O'Hare, the capacity or throughput of that airport can vary from 90/hr, depending on weather, aircraft mix, etc., to as much as 190/hr on a good VFR day. Ask yourself which capacity the users will use for their flight planning. So a small hiccough will cause delay for five, six or seven hours. The Integrated Flow Management system would tie in with the aircraft flight management systems which airlines want to buy to optimize the aircraft's flight and fuel-consumption results, and optimize the situation and use of the airport for the whole group. There are a variety of things we expect to get out of this, primarily tying together a whole series of optimizations. One thing to do is assist the controllers to select the optimum configuration of runway operation for a given situation of weather, traffic expectations and other factors.

Bottom lines are relatively simple. There are near-term gains from procedural improvements and current technology. We think gains as large as 6% will come from levels of automation than the community is currently thinking about. It will take Integrated Flow Management and an exquisite integration of the aircraft capabilities, the enroute system and the airport system. A realtime network of winds aloft and temperature should save somewhere between 1 and 3% of the fuel bill for US air carriers; that's between $100 and $300 million a year. The technology is here, both to acquire the data and the digital communication. We want to do this better and the carriers will have to do it better to maintain a profit situation.

Even after all these years, we need to understand that there is a demand/delay/fuel cost relationship. Pressure on the system doesn't do it. People need to understand what the limits are.

<u>Paul A. Petzrick, Director , Office of Shale, Department of Energy</u>- Yesterday I got a new job to add to that introduction; I became program manager for the Union and Tosco agreements at the DOE. The outlook for oil shale is a hell of a lot of hard work. It's going, but think of what we've been through with Union. I received the first unsolicited proposal at ERDA five years ago for that 10,000 BPD module that is just being constructed on East Middle Fork of Parachute Creek. It is scheduled to go into production in 1982.

At the same time when I first came in to the Office of Commercialization, I received an unsolicited proposal to assist Tosco with the construction of the Colony Project. We did all we could to help them for five years; we finally have been able to make a loan guarantee award to Tosco for 75% of their 40% share of the project. I don't think the project would have ever gone if Exxon had not come in with their immediate $400 million toward the balance of the $3 billion it will take to build the Colony project. So the outlook for oil shale is a lot of money, a lot of hard work, and a lot of guts.

Oil shale is the nearest geologic relative we have to petroleum; it is the

best alternative by every analysis that I've seen. It is the best source for synthetic jet fuel. It offers the best price. But the most important thing to me, and I think to many of the major oil companies, is what we call "strategic hedge". We saw a figure here today from USGS of 58 BBbl; we have resources, not reserves but resources, of 25 gal/ton or more in the Green River formation of a thickness for existing mining, of 600 BBbl. Additional resources might result in production of 2.2 trillion Bbl. We have very limited knowledge about the oil shale resources of Alaska; from work done there by the Navy in the 50s and 60s, we think it might be somewhere around a trillion Bbl. We have figures on Eastern shale which run between 3 trillion and 40 trillion barrels. So much that it really isn't important what that figure is right now. It's one hell of a big resource and it's in this country.

Whatever the situation, we will be getting into a tighter energy situation in the world. From the strategic view, it is nice to be able to rely on that you have inside your borders.

Referring again to the money, it has become more expensive to develop large energy projects. It was one thing for a company to take a chance on a relatively few hundred million dollars when it appeared the payback might occur in a year or two. It is quite another thing to talk about multi-billion-dollar projects in countries which have problems with political stability, territorial integrity and so forth, and payback does not occur for several years.

Now, oil shale in Colorado and Utah is not immune to those problems; it is still subject to the political vagaries of our own system. A company could make all this investment and then be shut down either through a court suit, or for other reasons not be able to operate their plant and get their return. They are not faced with an easy choice, but there is a place in our future for oil shale.

I won't get involved in projecting figures. The companies all have different interpretations, but fifteen of the twenty largest oil companies are actively involved, in one way or another, in oil shale. They all have the message; they have an investment in refineries and they need to assure feedstock.

I'll simply introduce some of the handouts here and let you draw your own conclusions from them. One is called, "Guide to Oil Shale", written for laymen like state legislators. Another is the final edition of the project book that we did early in 19[illegible]. It lists the current projects and I will run through a few to put their relative importance into your minds.

The first in the book, Buffalo Trace, is a study of eastern oil shale. It was very controversial because we pitted a western technology, Paraho, against the most famous eastern technology. It proved that liquid fuels can be forced from eastern shale, but at a price, with high-pressure systems, catalysts, and hydrogen to get the production. There is considerable cost advantage to accepting lower production, using one of the simpler systems at atmospheric pressure. Perhaps most important, you must consider something like a cogeneration facility to recover heat from the residual carbon and convert it to electricity or other marketable products, and recover marketable gases. Eastern shale oil is perhaps ten years away for serious operation, but that's not so bad when you consider what I just said about Union.

Looking at a couple of the important western projects and what is happening, because most people still seem to think of oil shale as something that is coming. Union has mined out all of the galleries for the change house, repair shops, adits to the production galleries and the main storage gallery. They've constructed their mine bench and the foundation for the module is under construction. They have participated with Exxon and Tosco in construction of the access road from Parachute to the head of Parachute Creek, about 20 miles of 50-ft-wide pavement. The last five miles up the side of that mountain was a real bear. There are two or three hundred pieces of equipment working between Battlement Mesa, the support community for the Colony project, across the river from Parachute, and the head of the creek. There are between one and two thousand workers on the scene. The time has arrived when we are making a serious attempt to build an oil shale industry in this country.

The technologies must work out or be fixed to work; it depends on continuing favorable treatment by federal, state and local government. In that regard, at Cathedral Bluffs, with Occidental and Tenneco working on lease Cb, they have not yet selected a technology, but they have spent over $120 million on the site, they have their production shaft down to 1707 feet, and they are going for 1867 feet. Now that's not bad compared to the fifteen thousand feet we heard earlier here today, but this is a 29-ft diameter production shaft, quite different from drilling a tube.

We always hear about water problems with shale. Well, they have one; last month they pumped over 69 million gallons of water just to dewater the area for their shaft construction; just the ventilation, services and production shaft---not their major mine. They have just cleared their 139th permit. Rio Blanco county just took a look at some of their sociological problems and adjusted the filing fee up to $2 million. These are the kinds of problems that the companies are being faced with. Nevertheless, shale oil remains attractive to them.

No matter what we say about these projections--and I am one of the greatest skeptics about putting numbers into a computer and believing what is coming out--the corporate officers of several of our largest corporations, who control the majority of our capital that can be invested, are putting a significant part of that potential into shale oil. Some of the major investment firms have concluded that, after investment in petroleum development and money spent on building new electric power plants, the next major investment in this country is the money for construction of shale oil facilities.

I think I can assure my friends here from the past, with whom I've worked on jet engine fuel, that the feedstock is coming. To summarize where oil shale is going: We are going to have it, it's a lot of hard work; it will cost a lot of money; it's still the cheapest thing to do.

Discussion of Slides: At the Chevron Clear Creek site, these people have to revegetate their shale pile after they mine and expose this stuff. The country didn't support that much vegetation to start with. For a feel of the access problem, the difference in elevation of this Taylor Slope is a little over 6,000 ft, which explains the five miles of switchbacks to get up there.

This is the mine bench for the Colony Project. They are shoving out of the mountain a road and rockspots. They are doing a marvelous job and, after the exposed material has oxydized, you won't be able to detect that a major project is going on there. That doesn't mean that we aren't going to change things out there. This guy (prospector and mule) is the only one who lives up there and we're certainly going to change his lifestyle. We will have to accept some changes to get oil shale.

Q- On the question of money--there was an earlier figure of an investment of about $70,000 per Bbl/Day for the Thornton project and you mentioned $3 billion for our Colony Project--I keep hearing numbers that are higher. If it's not $100,000/Bbl/Day, it's even more.

Potter- What these numbers are really proving to me is that there aren't any smart people in the shale business because smart people would have built their plants with pre-1969 dollars, at $8-10,000 per daily barrel, and sold the oil at post-1973 prices. Just in the five years I've been working on it the price tag has probably gone up from about $15-20,000 to, as you say, over $100,000 per daily barrel. That's absolutely right, that's happened in five years. Within the time period it takes to build a plant, I tell my people that the interest on $3 billion, during a coffee break, would pay the annual salaries for everybody in the office.

When do you decide you can't stomach this? Although there's some levity on the pre-1969 and post-1973 prices, when you're locked in on the next best alternative to petroleum, then it really doesn't make any difference. That's going to be the cheapest way to go. In five years, we may have to do it for $300,000 per daily barrel, but we should go ahead now at $100,000.

End

Appendix D

Until January 27th: 3101 N.E. 47th Court
Fort Lauderdale, FLA 33308
305-772-6[illegible]

After January 28th: 6005 Bayview Ave., #[illegible]
Willowdale, Ontario, M2M 3[illegible]
416-223-7[illegible]

Mr. Charles L. Blake, Federal Executive Fellow
Mellon Institute, Energy Production Center
1925 N. Lynn Street
Suite 1200
Arlington, Virginia 22209

Dear Charles-

This letter is in long-hand because I am in Florida (thank the Lord) and don't know where I can get it typed. I would be grateful if you could have one of your staff type it and let me have a xerox copy for my record. Your typist could phone me (see above) to clarify it where my writing is illegible.

Also, because I am away from home I haven't reference material to check dates but I believe the ones mentioned are correct.

You asked if Air Canada uses any special precautions in using wide-cut fuel. Apart from what I mention in the attachment, such as including an anti-static additive in the airline's fuel specifications, I have been away from the airline too long to say what it does today.

I suggest that you write to -

Mr. D. Jennett, Senior Vice President Operations
Air Canada
Place Ville Marie
Dorchester Boulevard West
Montreal, Quebec

and ask him if he could let you have a copy of that portion of Air Canada's Operations Manual covering the handling of fuel.

I would also appreciate it very much if you could let me have a copy of your final complete report. It will be most interesting and helpful for future reference.

Best regards,

Jack Bynum

Reply to Letter from [illegible] Blake Dated [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

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[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

fuels [illegible] and treats both with the same respect as it d[illegible].

BUT THERE IS ONE THING TO REMEMBER: AIR CANADA'S FUEL HAS ALWAYS INCLUDED AN ANTI-STATIC ADDITIVE since thoroughly investigating its benefits over 20 years ago. This may be why Air Canada has not encountered any trouble in using either fuel or a mix.

Perhaps a bit of history concerning the use of an anti-static additive might be of interest.

Twenty or so years ago a few explosions that occurred with [illegible]

[illegible]

[illegible]

Several oil companies had anti-static additives available, and [illegible]. They [illegible] from the additive [illegible].

In our investigation of the [illegible] we found that some of the additives were not compatible with [illegible].

[illegible]

We finally got all the airplane, engine and gauge manufacturers to agree that the additive ASA3 would be acceptable so that was the one selected by I.A.T.A. and its use strongly recommended by the airlines.

Immediately [illegible] was not the Shell product, that company started a campaign stating that certain hazards would occur in using an anti-static additive. This frightened some U.S. airlines from including it in their fuel specifications.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Since we were the first foreign customer for a turbine aircraft we convinced the British government to permit certification of the Viscount when using either JP1 or JP4. For several years we used only JP4, but eventually when satisfied that there was no hazard when using kerosene during flight we relaxed our requirement and permitted the use of either fuel. The selection became chiefly one of price.

CONCLUSIONS RE JP4 vs. JP1

If there is availability of JP1 and the price is acceptable, its use is preferable, but its additional advantage from a safety standpoint is not sufficient to preclude the use of JP4 if its availability is better and the price is acceptable.

Air Canada has been using JP4 for [illegible] years and JP1 for [illegible] years. It might be remembered that up to 1960 or 1961 Air Canada was the sixth largest (passenger miles flown) airline in the free world and is still about [illegible] in size.

With the existing fuel supply situation I believe that JP1 will remain preferable in the U.S.A., but in other countries it might be preferable to use JP4 at some locations so the government should keep its options open to handle changing situations in the future.

OTHER COMMENTS ON THE [illegible] LETTER

In the last paragraph of your letter of [illegible] you asked for my views on both the world energy market and concern about the U.S. position.

It would be presumptive on my part to expect any views of mine would be of any value to your study with all the other experts in these areas helping you. However, since you asked for them, you can consider them as the viewpoint of an interested foreigner.

First, considering the existing production, consumption and resources in petroleum on this continent it would appear that the consumption of conventional oil and gas has already peaked out and such sources will be finished within 50 years. The exploitation of tar sands and oil shale will probably prolong the life of the petroleum industry for another 50 years.

In the meantime I believe that uranium fueled power plants will increasingly be used over the 50 year period from now to produce electricity, in spite of the opposition of the public.

The only real competition to the use of the uranium reactors will come from the increasing use of coal to produce electricity, oil and gas, but the destructive effects on the environment both in the air and on the terrain will result in very stiff opposition from the public, and rightly so. Its use will probably reach its maximum about fifty years from now and then remain constant thereafter.

With the work going on to develop the fast-breeder as an energy source it will probably start to replace the uranium reactors in fifty years and its use peak in about 100 years.

It is hoped that by that time the use of "fusion" will have become practical, so it and solar energy, which latter will have been developing gradually from now on, will finally predominate as the main sources of energy in 200 years.

The use of other sources of energy such as hydro, wind, tide, geothermal, refuse, and crops will be relatively insignificant from a continent-wide standpoint although each will undoubtedly be used successfully in particular areas.

The advantage of expressing the above views is that we'll be dead before we know if they are right or wrong.

Now to look at the world-wide situation:

It appears that of the "developed" countries, three stand out as the potential "greats" of the future from an energy production standpoint. They are the U.S.S.R. and the U.S.A. on the basis of current production and known reserves, but many believe that eventually China will become a strong rival to both.

Some Candian experts currently say that of the known resources; the U.S.S.R. has double the petroleum, a bit over double the natural gas, and triple the coal resources of the U.S.A. The U.S.S.R. is also strategically located to be able to take over the Persian Gulf if it should ever feel the need.

Of the so-called "developing" countries only two areas have energy resources of appreciable magnitude. Saudi Arabia and the Persian Gulf have nine times the petroleum and a bit more gas than the U.S.A. but no coal. The other area, North Africa, has almost double the petroleum and half as much gas as the U.S.A., and again no coal.

Reserves of the rest of the world are currently very small and with rapid escalation of the costs of exploration, development, processing, transportation and interest on borrowed money, it means that the capital cost of producing new sources of energy, petroleum and otherwise, is making it practically impossible for the developing, and many of the developed countries, ever catching up with their energy needs. If they can't meet these industrial energy requirements they will never change from a developing to a developed country.

It is appreciated that many of the developed countries do help those less endowed in many ways, but seldom where it really counts from the standpoint of making them self-sufficient. We give products manufactured by ourselves because it helps our own labor situation, or we give or loan money to them if our own country gains some benefit from so doing.

In any event it appears to me that the gap between developed and developing countries will continue to widen, with the final result that many of the developing countries will be assisted to such an extent that they will finally become controlled by specific developed countries. It would be impolite to call them "colonies" again. They will be "independent" and enjoy a status such as Afghanistan, Hungary, Poland, etc.

I believe that our best hope is that China, with technical help from our continent, will develop sufficiently fast to so worry the U.S.S.R. that it will have to concentrate a large part of its efforts on its Eastern borders instead of being free to move Southward or Westward.

Many years ago, someone in England said "Beware of the bear that walks like a man." This is still true today.

Therefore, any help we can give to China to help it develop its energy resources should be to our own advantage as well.

COMMENTS ON VOLUME 1 - EXECUTIVE SUMMARY

Since you asked for comments on Volume 1 here they are:

Firstly, I'd like to say that it is an excellent presentation so I hope that you will not take any of my comments as a critisim. They are merely the reaction of one reader.

In the opening paragraph one gathers the impression that the oil industry really started in the Ohio valley with Titus first oil well in 1859.

Anything one reads or is taught of a historical nature must be taken with a grain of salt if it is written by one's own countrymen.

Canada's petroleum industry says that James Milles Williams was the father of the North American oil industry because he successfully produced oil from a well early in 1858 in Enniskillen Township of Ontario and refined it in his 1857 refinery on the shores of Black Creek nearby. Williams operations was the first North American integrated oil company as it was involved in exploration, production, refining, and marketing. It eventually became the Canadian Oil Company in 1860.

We in Canada are told that in 1859 Col(?) William Drake drilled a hole in Titusville, PA, and found oil at a depth of 70 feet. By the end of 1960 the U.S. industry was providing 40 to 80,000 m^3 of oil per year while Canada was still only providing 1,600 m^3 per year.

So although the U.S., within a year of starting its oil industry, rapidly outproduced Canada, it was not the first. This historical view is not really important, but only mentioned here to illustrate how every country, city or town thinks it is first or the best in something.

Reference is made to the third paragraph on page 6. While not disagreeing with what is said, I believe it could be mentioned somewhere that prices do not always follow the law of supply and demand. Prices may be controlled politically as by OPEC and also in Canada to some extent. The next paragraph concedes this in a way, without mentioning "politics." It takes page 8 before it is mentioned that prices do not necessarily depend on supply.

Reference is made to page 9. It is not clear if you mean only Jet A or JP1 when you say "aviation", "jet fuel" and exclude JP4 or Jet B. You may be considering the latter along with "gasoline." While conceding that JP4 is a wide-cut gasoline it should, in my opinion, be included as a "jet fuel" because theremight come a time in the future when its use might greatly increase. Actually it would be better to say "kerosene"or "wide cut" because their use will depend to some extent in the future on the demand for the various portions of the barrel. In any event you should make it clear the type of fuel you are talking about when you say "jet fuel."

Reference page 11, paragraph 19. You say "Aircraft DOC with hydrogen fuel are comparable to those with avjet but airport costs for liquefaction and handling are considerable." If the liquefaction and handling costs are high, the airline is going to pay for it by higher airport charges or some other means. (It is the total operating cost that counts, not just DOC, which was established about forty years ago and doesn't even include cabin attendant costs.) I do not believe that the airlines will use liquefied hydrogen within at least the next fifty years (in spite of some enthusiasts at Lockheed).

Reference page 14 "Jet A...", et seq. See my previous comments relating to the degree of safety of Jet A over Jet B and use of an anti-static additive to reduce handling hazards. As mentionad elsewhere, I believe the options should be kept open for the airline to use either Jet A or Jet B as future

conditions dictate. But I believe that the use of an anti-static additive should be mandatory in both jet fuel specifications.

To conclude - Your report is exceptionally good, comprehensive, interesting, and very well presented. My comments are insignificant.

J. T. Dyment

Appendix E

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ALEXANDER R OGSTON
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Aviation, Marine & Petroleum Consultant

1 PARK STREET
TENAFLY N J 07670 U S A

May 3[illegible], 199[illegible]

Mr. Charles L. Blake
Federal Executive Fellow
Federal Aviation Administration
800 Independence Avenue
Washington, D.C. 20591

Dear Mr. Blake:

During our meeting and discussion in your office when I was in Washington, [illegible], you showed me the most interesting letter and commentary that you had received from Mr. J.T. Dyment, retired Chief Engineer of Air Canada (formerly Trans-Canada Airlines or TCA). I first met Jack Dyment around 1945/46 when he was in charge of maintenance at the airline's base at Winnipeg. Exxon's Canadian affiliate was TCA's principal supplier of fuel and lubricants and I maintained contact with Jack Dyment through the years until his retirement, circa 1970. Since then we have remained very good friends, despite our opposing opinions on the JP-4/Jet B versus Jet A/kerosene safety issue, or rather controversy.

In order to set the record straight, I would like to comment on a few points in Mr. Dyment's letter, especially his remarks relating to anti-static additives which, [illegible], are quite misleading. I have turned up some of my old files and I can state that the following is the correct and, I feel, unbiased history of the anti-static additive development.

Firstly, while I and many others agreed that anti-static additive was necessary to minimize the risk of a fuel tank vapor explosion when refueling with Jet B (i.e. JP-4), I and most of the U.S. airlines did not consider it necessary or even desirable where Jet A (i.e. kerosene) was involved (and assuming no residual JP-4 present in the aircraft tanks), because, normally, flammable vapor will not be present. Static build-up results from the passage of the fuel through filters and usually the more efficient the filter and, of course, the higher the rate of flow, the greater the generation of static electricity. In practice, high static build-up does not result from flow thorough pipelines and, in fact, existing static charge tends to be relaxed during the flow through pipelines or the fueling hoses.

The complete separation of undissolved water from kerosene is not as easy to achieve with kerosene as is the case with Jet B, due to the lower viscosity of the latter and also the greater differential between the respective densities of Jet B and water, as compared with kerosene.

During the original research and laboratory work to develop an anti-static additive, both Shell and Exxon had developed possible additives. Both were tested extensively and both showed some deficiencies. However, Shell's ASA-3 was the additive chosen primarily because it provided a greater increase in conductivity at lower concentrations and at lower cost than the Exxon additive.

From the beginning, there was concern about the ASA-3 additive being a surfactant and thus having an adverse effect on the ability of the filter/separator to remove water. A new class of filter/separator emerged which was more effective because these newer type filter/separators had longer lives before being disarmed by the ASA-3. But even the new filter/separators are still disarmed in time.

Another adverse effect of ASA-3 (and possibly of all anti-static additives) is that it tended to be lost during pipeline transmission and other bulk transfers. This

means that the additive really has to be injected into the fuel at or near the airport. Overseas, where the oil companies provide into-plane fueling service, the supplier could cope with this problem of injecting the additive at or near the airport. Domestically, where the U.S. airlines or third parties did the into-plane fueling, injection of the additive at the airport presented a problem that the U.S. airlines did not want to take on. This fact, coupled with deactivation of filter/separators and the use of kerosene rather than JP-4/Jet B, caused the U.S. airlines to resist the use of ASA-3. Some of them also felt that the additive promoted pickup of impurities from the system and cited this as a further reason for opposing its use. Again, a phenomenon more likely to occur with kerosene than with Jet B).

Exxon U.S.A. supported the position of the U.S. airlines and did not use ASA-3. Overseas, including in Canada, Exxon affiliates generally do use ASA-3 because they can control the point of injection. Furthermore, at overseas locations, Exxon is a member of a number of joint ventures where the use of ASA-3 is mandatory because the Exxon fuel is commingled with competitive fuel containing ASA-3.

Although I retired from Exxon International some years ago, the foregoing are the facts as I clearly recall them. I trust that you will agree that Mr. [illegible]'s implied criticism of Exxon's role in the matter is unjustified and can only be due to misunderstandings, while overlooking the fact that all the U.S. airlines operate on kerosene and not JP-4/Jet B as in Air Canada.

Yours sincerely,

Alex Ogston

Alexander [illegible] Ogston

☆U.S. GOVERNMENT PRINTING OFFICE: [illegible]

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